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EFFECTS OF SIMULATED SURFACE EFFECT SHIP MOTIONS ON CREW HABITABILITY. PHASE II

VOLUME 3
VISUAL-MOTOR TASKS AND SUBJECTIVE EVALUATIONS

Henry R. Jex
Richard J. DiMarco
Warren F. Clement

Prepared by
SYSTEMS TECHNOLOGY, INC.
H. R. Jex
R. J. DiMarco
W. F. Clement

COMMANDER, NAVAL SEA SYSTEMS COMMAND
(PMS-304)

Department of the Navy
P.O. Box 34401, Bethesda, MD 20084

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SES motion simulation	Ship motion simulation
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

From July through September 1975, a series of ship motion simulation experiments was conducted using the ONR Motion Generator at Human Factors Research, Inc., Goleta, CA. These experiments (designated Phase II) were part of a program sponsored by the Surface Effect Ship Project Office to establish the effects of SES motions on the health and performance of crew members. Nineteen U. S. Naval enlisted personnel were exposed to motion for periods up to 48 hours in a closed test cabin. The motions simulated were those predicted for a large SES encountering starboard bow seas at high speeds (i.e., 80 kts at Sea State 3, 60 kts at Sea State 4, and 40 kts at Sea State 5). The personnel were subjected to a battery of visual-motor tests during motion and static conditions, and were requested to complete subjective evaluation forms. Results of test performance and subjective evaluation are presented.

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18. SUPPLEMENTARY NOTES (continued)

motion on crew health and performance. Other organizations preparing the companion volumes are Naval Sea Systems Command (PMS-304), Human Factors Research, Inc., and Naval Aerospace Medical Research Laboratory Detachment.

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PREFACE

This project was Phase II of a large-scale investigation of high-speed-ship habitability (crew motion effects) by the U.S. Navy Surface Effect Ship Project (SESP, Code PMS-304 located at the David Taylor Naval Ship Research and Development Center, Carderock, Maryland). Activities of all participants were closely directed, coordinated, and participated in by two key SESP personnel:

LCDR J. Michael Vickery, Royal Navy (PMS-304-40A)

Mr. Warren Malone (PMS-304-42)

The other Naval agencies participating (along with their key roles and personnel) were as follows:

Naval Aerospace Medical Research Laboratory, Detachment at Michoud, Louisiana (NAMRLD)

Crew volunteers and medical tests, medical monitoring, head motion measurements.

Capt. Channing Ewing, MC, USN; CDR Paul Majewski, MC, USN; Dr. Dan Thomas, M.D.; Dr. John C. Guignard, M.D.

For privacy reasons the names of the 19 Naval enlisted personnel who volunteered as test crewmen cannot be listed, but their perseverance despite sometimes unpleasant environments and tasks deserves commendation.

Naval Ship Research and Development Center, Ship Dynamic Simulation Branch at Carderock, Maryland (NSRDC)

Recording system, motion tapes, and analyses

William Smith, Robert Stanko, David Milne

The test facility was developed and operated under Office of Naval Research (Code 444) sponsorship by Human Factors Research, Inc. (HFR) at Goleta, California. HFR also conducted several experiments and coordinated all logistics. The principal personnel supporting this Phase II work were: Dr. James F. O'Hanlon, Mr. M. L. Seltzer, Dr. A. Harabedian, Mr. Glenn Sanderson, and Mr. Greg Bailey. At Systems Technology, Inc., several persons besides the authors were heavily involved in the work reported herein: Jeffrey R. Hogge, James Nagy, Daniel Swanburg, and Wade Allen.

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SECTION I

INTRODUCTION

A. GENERAL

This third volume on the Phase II Surface Effect Ship (SES) motion simulation describes the battery of visual-motor tests and subjective evaluation forms, presents the effects of simulated SES motions thereon, and, where possible, ties in the present results with earlier studies in this series of SES habitability investigations (Refs. 1-5). The tasks and evaluations covered in this volume were the responsibility of Systems Technology, Inc. (STI), who developed them in earlier phases of this and other work, monitored their execution by the test personnel, and analyzed the results.

The reader is also referred to:

- Volume 1, "Summary Report," for a brief overview of the program and results.
- Volume 2, "Facility, Test Conditions, and Schedules," for detailed descriptions of the Motion Generator [operated for the Office of Naval Research (ONR) by Human Factors Research, Inc. (HFR) at Goleta, California]; time histories, spectra, and statistics of the simulated motions; and details on the daily work/rest schedule, as well as the overall run schedule (Ref. 20).
- Volume 4, "Crew Cognitive Functions, Physiological Stress and Sleep," for a detailed description of a separate group of tasks and measures under the responsibility of Human Factors Research, Inc. (Ref. 19).
- Volume 5, "Clinical Medical Effects on Volunteers," for complete data on crewmen, incidences of motion sickness, medical logs, and time histories of head motions measured under various motion conditions and postures (Ref. 18).

For convenience of presentation and reading, this volume presents each task as a self-contained subsection, complete with task description, results, and discussion. Section II describes the visual-motor tasks, and Section III the subjective evaluations. A concise summary of all key findings and conclusions and recommendations are given in Section IV.

B. OBJECTIVES

Before proceeding to the tasks and results, one should recall the basic objectives of this Phase II program (Ref. 7):

"1. The primary objective of the Phase II Simulation Program is to increase and improve the available data base on the effects of predicted 2KSES motion environments on the performance and health of humans.

2. Secondary objectives of the program are:

   2.1 to improve understanding of the relationship between particular characteristics of the predicted environment and the observed or measured effects on volunteer subjects.

   2.2 to improve understanding of the contribution which adaptation processes may play in determining the acceptability of motion environments."

During Phase I four naval SES crewmen from the Surface Effect Ship Test Facility (SESTF) at Patuxent, Maryland, had been put through an exploratory series of simulations designed to evolve tasks and procedures for use in simulated rough water/high speed conditions characteristic of bow sea (sea from 135 deg, starboard bow) SS 3/80 kt, SS 4/60 kt, and SS 5/40 kt (Refs. 5 and 6). They proved capable of running for periods of several hours even at SS 5 conditions, so in Phase IA the same four crewmen underwent 1-1/2 to 2 day runs at conditions indicated to be probably tolerable for such periods, namely SS 3/80 kt, SS 4/60 kt, and SS 5/40 kt (the last case being somewhat arbitrarily attenuated to crudely simulate effects of a possible ride control system). As reported in detail in Ref. 6, these SESTF crewmen adapted gradually to the somewhat unusual motion environment and learned to cope with normal life support functions such as eating, drinking, moving about, and sleeping. They could perform with varying degrees of success all of the tests in a battery of simplified, but operationally relevant, tasks, such as navigation plotting, cryptography, auditory vigilance, lock opening, keyboard operations, tracking, and equipment maintenance and repair. Although there was some evidence of general muscle and eye fatigue due to the continuous motions, performance did not show pronounced dropoffs with time over the 48-hour periods tested in Phase IA.

However, two main shortcomings of the Phases I, IA tests existed from the outset: 1) the very small sampling of well-motivated crewmen made it difficult to generalize the results to a wider population; and 2) the existing ONR-HFR Motion Generator (MoGen) could not replicate the higher acceleration and velocity portions of the computed motion waveforms after the larger cab (which had eating, sleeping, and lavatory facilities for two persons, suitable for long runs) was installed. Thus, clearing up these deficiencies was the primary goal of Phase II.

C. MOTION CONDITIONS

1. Facility

Between Phases IA and II the Motion Generator heave drive system was extensively modified to permit heave accelerations of +1.0 to −0.8 g velocities of ±17 ft/sec, and displacements of ±10 ft, with very smooth frequency response over a 0.10-3.0 Hz range and beyond (Refs. 4, 8, and 10). In addition, certain angular structural modes were damped by special feedback compensation (see Ref. 9). The dynamic performance of the modified Motion Generator is presented in detail in Ref. 10, and a summary is given in Vol. 2 of this series, along with typical time traces of the commanded and measured motions, so no further details will be given in this volume. Suffice it to say that the commanded motions (which had been computed by the Oceanics, Inc., program and prerecorded for playback) were quite faithfully followed in waveform, albeit with scale factors not always 1.0 as desired, due to inadvertent calibration errors (see Vol. 2 for details).

2. Conditions

Due to circumstances explained in Vol. 2, identical motion conditions were not run for each of the three teams (one per month) tested in Phase II. For purposes of correlating various results in this volume with motion conditions, a matrix of conditions has been agreed on among the principal investigators, as given in Table I-1. The typical (rounded) g-level for the runs in each cell is listed in parentheses. Notice that on one diagonal there are three different waveform conditions (SS 3, SS 4, and SS 5) at 0.19 G_z; the attentuated SS 4 and SS 5 conditions were run as a subexperiment to isolate the effects of g-level from the effects of waveform.

Putting the conditions in order of ascending total rms acceleration gives Table I-2, used throughout most of this volume to order the effects of motion. The fact that the conditions are ranked by rms G_z does not mean intensity is the sole determinant of the degree of observed motion effects. In fact, as earlier discussions point out (e.g., Refs. 11 and 12), there are a host of attributes for any given motion situation which may influence, in diverse ways, such human problems as motion sickness, visual-motor task performance, subjective ride qualities, and general habitability. It is beyond the scope of this report to discuss these in detail, but a few relevant points will be made:

- Motion sickness seems to be primarily caused by vehicle motions in the 0.10-0.60 Hz range with the greatest sensitivity in the 0.2-0.3 Hz range.

- Visual-motor activities (involving fixation of fine details by the eyes, control of muscles to move about, or precise manipulations of tools or controls) seem to be affected primarily by a wide spectrum of motions from 0.1 to 10 Hz, with especial sensitivity in the 2-6 Hz range.

- Subjective annoyance with the quality of ride is a complex function of several waveform properties, only vaguely understood at present. There is some evidence that sharp acceleration peaks beyond those normally encountered in walking or running (wherein peaks of up to about +0.4–0.5 G_z are encountered at 0.5 to 3.0 Hz frequencies) are the most annoying.

Accordingly, for those who may wish to speculate more widely along these lines using the results herein, we have added a few key heave acceleration statistics to the basic rms G_z values in Table I-2: the rms G_z in the "low" range, 0.1-0.56 Hz ($\sigma_{<.6}$), and in the "high" range, 0.57-10.0 ($\sigma_{>.6}$); the "characteristic frequency" of the waveform (defined as the frequency of positive-going axis crossings, f_0^+); and the frequency of exceeding +0.5 G_z peaks ($f^+_{.5}$).

TABLE I-1

MATRIX OF GROUPED TEST CONDITIONS

Level Name:	"Low"		"Medium"		"Full"	
Nominal Fraction‡:	"2/3"		"4/5"		"1"	
Actual Fraction‡ Range:	.65-.69		.77-.82		.89-.101	
Sea State	Month	Run	Month	Run	Month	Run
SS 3/80 kt		(.13g) B		(.16g) D		(.19g) E
	July	—	July	424, 455, 457,		
	Aug	483, 485		C 439,† 440†	Aug	487, 489
					Sept	525, 527
SS 4/60 kt		(.17g) F	"SS 4A"	(.19g) G		(.25g) H
	July	453, 454			July	446, 451
			Sept	529,* 530,* 532,* 533*	Sept	540,* 541,* 550
SS 5/40 kt	"SS 5A"	(.19g) I				(.28g) J
					Aug	494,† 496†
	Sept	535,* 536,* 538*			Sept	543,* 545* K 547

Notes:

◯ Denotes code for some data presentations; A = static

( ) denotes nominal rms G_z for each group

‡Fraction of source rms heave acceleration

†Denotes 1-pump runs

*Denotes 6 hr runs; others typically 20-48 hr

TABLE I-2. SOME HEAVE ACCELERATION CHARACTERISTICS OF GROUPED TEST CONDITIONS

(Numbers in parentheses denote rank from lowest to highest in column)

CONDITION NAME	RMS G_Z OVER WHOLE SPECTRUM σ (g)		RMS G_Z OVER 0.1-0.56 Hz RANGE* $\sigma_{<.6}$ (g)		RMS G_Z OVER 0.57-10.0 Hz RANGE* $\sigma_{>.6}$ (g)		CHARACTERISTIC FREQUENCY (Up Zero Crossings) f_0^+ (Hz)		FREQUENCY OF EXCEEDING +0.5 g LEVEL $f_{.5}^+$ (Hz)		MSI WEIGHTED RMS G_Z† σ_{MSI}	
Low (2/3) SS 3	.13	(1)	.067	(1)	.11	(1)	.98	(8)	0	(1)	.021	(1)
Medium (4/5) SS 3	.16	(2)	.085	(2)	.13	(2)	.93	(7)	.063	(2)	.026	(2)
Full (1) SS 3	.19	(4)	.10	(4)	$.16^+$	(6)	.91	(6)	.11	(5)	.032	(3)
Low (2/3) SS 4	≈.17	(3)	≈.10+	(3)	≈.14	(3)	≈.88	(5)	(?)	(3)	.048	(4)
Medium (4/5) SS 4	.19	(5)	.11	(5)	$.16^-$	(5)	.83	(4)	.12	(6)	.054	(5)
Full (1) SS 4	.25	(7)	.14	(7)	.21	(7)	.79	(3)	.17	(7)	.071	(6)
Low (2/3) SS 5	.19	(6)	.12	(6)	.15	(4)	.73	(2)	.10	(4)	.076	(7)
Full (1) SS 5	.28	(8)	.18	(8)	.22	(8)	.70	(1)	.18	(8)	.113	(8)

Notes:

All values shown are typical rounded averages; for detailed values see Vol. 2.

All values are measured, and do not presume Gaussian distributions.

*$\sigma_{<.6}$ includes ISO bands from .025 to .50 Hz (.56 Hz upper edge); $\sigma_{>.6}$ includes ISO bands from .63 to 10.0 Hz (.56+ Hz lower edge); $\sigma = (\sigma^2_{<.6} + \sigma^2_{>.6})^{1/2}$

†Adapted from Table 2 of APL/JHU Report SES013 (Ref. 17).

Figure I-1 further summarizes heave acceleration statistical parameters of tested conditions with plots of: a) typical spectral densities; b) corresponding ISO format spectra; c) rms G_z vs. f_0^+; d) $\sigma_{<.6}$ vs. $\sigma_{>.6}$; and e) G_z amplitude vs. frequency of exceedence ($f_{G_z}^+$). Additional details on such statistics may be found in Vol. 2.

D. EXPERIMENTAL DESIGN

A relatively simple experimental design was originally planned, in which each of three teams of four young seamen would go through a series of alternating static and motion runs of two days each. One pair of crewmen would ride the MoGen cab, while the other pair performed the same tasks in an almost identical "static" cab. Previous experience on Phases I and IA had shown that an alternating static-motion-static-motion paradigm was required in order to establish the "likely static baseline" from which to judge the effects of motion due to task learning effects and adaptation to the living conditions. The motion severity was to be systematically increased from SS 3 to SS 5 for all subjects, to facilitate any adaptation to more severe sea states that might occur.

With three teams of four men each, this would result in twelve subjects per cell of the motion condition matrix (SS 3, SS 4, SS 5, and static), a number felt to be quite adequate to judge the general effects of motion on relatively naive naval personnel.

However, for a number of practical reasons, discussed in Vol. 2, this experimental design was not carried out as planned. MoGen overheating resulted in some runs being made with one pump only; miscalibrations resulted in excessively attenuated intensities in July; some crewmen withdrew early due to high susceptibility to motion sickness; and the subexperiment mentioned previously with 0.19 g for SS 3, SS 4A, and SS 5A and a number of 6 hr runs was instituted in September only. These, plus the unfortunate loss of significant portions of the subjective rating data due to forms incompletely filled out or lost, rendered impossible the analysis of the experiment as a full factorial design with subjects as their own controls, as originally planned. In reading the following report (and Vol. 4 as well), please keep in mind these considerations, and the need to be flexible in

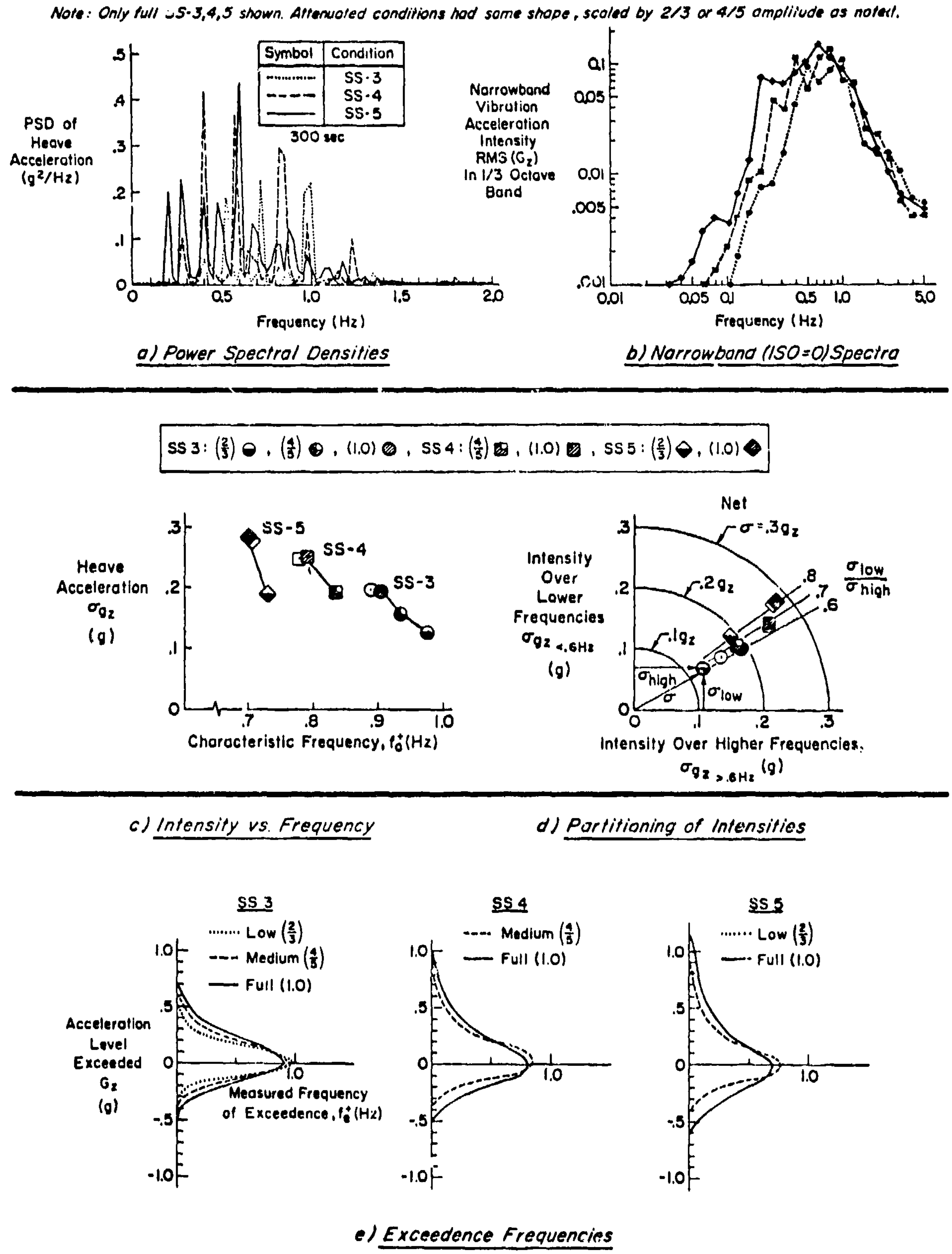

Figure I-1. Summary of Statistical Parameters of Measured Heave Acceleration data interpretation to squeeze the "most likely conclusions" from sometimes incomplete data.

A general comment on the series of 6 hr runs in September must be made at this point. It had become apparent that most of the effects of motion on task performance, motion sickness, and general living functions other than sleep would show up within several hours. Consequently, a series of 6 hr runs, at the rate of two per day (with different crews in the morning and the afternoon), was run in September. For all of the tasks discussed in this volume, the motion effects measured in the 6 hr runs were the same as for the first and second days of the 48 hr runs at a given condition; thus, all are pooled in the appropriate cell of Table I-1 and later herein.

E. TEST SUBJECTS

The test subjects were all volunteers assigned as Hazardous Duty Personnel at the Naval Aerospace Medical Research Laboratory, Michoud Detachment (NAMRLD). Most of them were just out of boot camp, with little, if any, naval sea duty at the time. All subjects had undergone a thorough medical examination at NAMRL Pensacola and had been screened to eliminate anyone exceptionally susceptible to motion sickness. (For details see Vol. 5 of this series, Ref. 18).

Three teams were tested, each team participating in the experiment over the course of about 1 of 3 consecutive "months" which corresponded closely with the calendar months July, August, and September. Each team consisted of 7 "crewmen" of whom 4 were selected as the primary test group, while the others served as backups. Selection of primary crewmen was based on satisfactory task learning and motivation demonstrated during the training period, any minor illness (as a negative factor), and likely compatibility of cabinmates, as indicated by each trainee.

In all, during the formal experiment, 19 different subjects were exposed to one or more simulated SES motion conditions for continuous intervals ranging from little more than an hour to two days. These 19 are identified in Table I-3 by the last two digits of their NAMRLD subject code. [Two of the August subjects (43 and 51) returned for part of the September tests.]

TABLE I-3

CREWMAN CODES AND DATA SYMBOLS

	CREWMAN NUMBER (NAMRLD Code)	NIGHT OR DAY SLEEPER*	DATA SYMBOLS	
			HAND PLOTS	COMPUTER PLOTS
JULY TEAM	49	N	○	M
	38	D	◺	&
	52	N	◇	P
	46	N	⏢	J
	47	D	△	K
	44	D	□	H
	35	D	⌓	B
AUG. TEAM	43	N	⌂	G
	50	D	⬭	N
	39	N	◊	C
	48	D	▷	L
	51	D	◸	[illegible]
	55	N	◗	V
SEPT. TEAM	60	D	⬯	X
	40	N	⬡	[illegible]
	56	D	⬥	T
	61	N	▽	Y
	59	D	◸	W
	57	N	◖	U
	43	D	⌂	G
	51	N	◸	[illegible]

*D = Day sleeper; nominal sleep period is 1200-2000

N = Night sleeper; nominal sleep period is 0001-0800

This table also indicates whether each subject was on a day or a night sleeping schedule and identifies the symbols (unique to each subject) used in all plots of individual subjects' data throughout this volume of the report. Two different symbols sets are used: one set for hand-plotted figures; the other for computer-plotted figures. This was necessitated by the absence of most of the originally designated (geometric) symbols on the standard list of computer symbols.

With these general points which concern all tasks kept in mind, we will now present one by one each test in the battery of visual-motor tasks.

SECTION II

VISUAL-MOTOR TASKS

A. OVERALL CONSIDERATIONS

1. Task Battery

An overview of the tasks in the STI visual-motor group is given in Table II-1 which lists number of trials in each test, number of tests per run, and the approximate time per test for each task in the STI battery (and also for the ratings which will be discussed in Section III).* The number of measurements on each trial ranged from one [e.g., on the Electronic Countermeasures (ECM) Tracking Task] to twenty (for the Dual-Axis Tracking Task), but not all measures were used in the final analysis. Nevertheless, all measurements logged have been put on IBM cards for archival reference, should this be needed for other scientific purposes (for example, the extensive array of static case data on nearly 20 different subjects constitutes a valuable normative data base for other experiments of this type).

Some comments on the choice of tasks is in order at this point. The various tasks given in Phase II were selected as being typical of a wide range of shipboard tasks, yet simple enough to learn in the brief training period preceding formal runs. It is recognized that most of the operational SES tasks requiring high skill, such as gunnery or electronic countermeasures operation, will have specialized personnel with extensive training, and thereby be fairly resistant to external stresses. In order to provide this level of task experience in a limited training period, we had to extract those essential features of the more complex tasks which were prone to motion interference.

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*The following definitions are used throughout:

"Task"	≡	The procedure or maneuver to be carried out, independent from the measures derived therefrom.
"Trial"	≡	Each attempt to obtain a score by performing a task.
"Test"	≡	Group of one or more trials on one task done at one sitting.
"Run"	≡	Each session of 6 to 48 hr with given motion conditions.

TABLE II-1. TASK/RATING SUMMARY

TASK/RATING	CODE	PERFORMANCE MEASURE	TRIALS PER TEST[a]	APPROXIMATE TEST TIME REQUIRED	RECORD MEDIUM[b]
ECM Tracking	E	Critical Instability Level, λ_c	5	5 min.	ODS[c]
Dual Axis Tracking	T	18 parameters/trial	3	10 min.	ODS,[c] TTY[d]
Keyboard	K	Computation time, T_K; errors; restarts	3	10 min.	KTD[e]
Lock	L	Time to open, T_O; restarts	1	1 min.	ODS[c]
Maintenance	M	Parts removed per minute	1	45 min.	ODS[c] and P-bag[f]
Load	P	(None)	1	5 min.	HEQ[g]
Kinetosis Rating	R	(None)	—	2 min.	HEQ[g]
Environment Rating	U	(None)	—	2 min.	HEQ[g]
Spec. Task Interference Rating	W	(None)	—	3 min.	HEQ[g]

[a]One test at each task was done per 24 hr of the long runs and per 6 hr run, except that two lock tests were done about an hour apart during the long runs and two ECM Tracking tests were done during the 6 hr runs.
[b]Qualitative ratings of motion interference were also given on HEQ for each task.
[c]Operator's Data Sheet.
[d]Teletype printout.
[e]Keyboard Task Data Form.
[f]Manila envelope in which removed parts were placed.
[g]Habitability Evaluation Questionnaire.

The earlier SES simulations at the NASA Marshall Space Flight Center (MSFC) (Ref. 2) and at Human Factors Research during Phases I and IA (Refs. 5 and 6) had evolved a good initial set of tasks, procedures, and measures. These include the ECM Tracking Task (involving precise, continuous adjustments of a knob with a meter display), the Lock Task (involving fine motor operations and good visual acuity), the Keyboard Task (involving complex operations on a small pocket computer keyboard), and vestiges of the Load Handling Task (involving one- and two-hand manipulations of a heavy, equipment-like black box).

New for this phase were the Dual-Axis Tracking Task (using a two-axis finger stick to control a continuously disturbed cross on a CRT display) and the Maintenance Task (using common tools to disassemble a piece of electronic apparatus). Each of the above will be separately described in the subsections to follow.

Wherever possible we attempted to give each task in the STI and HFR batteries a "scenario" or context relevant to SES operations. For example, the (HFR) Navigation Plotting Task used an actual nautical chart for the Pacific coast and offshore islands in the vicinity of nearby Santa Barbara, on which a set of possible-target bearings and ranges with respect to the SES were plotted, and the Keyboard Task operator was given a set of bearings and ranges of an approaching target from which he had to compute time-to-intercept. Following this overall scenario, the ECM task operator was told that his task simulated an ECM operator trying to prevent increasingly rapid radar frequency shift jamming by an approaching enemy aircraft or missile, and the Dual-Axis Tracking operator was told that his control efforts were to keep a tracking beam centered on an unseen enemy aircraft. Although these crude scenarios would not suffice for experienced personnel, well versed in a particular weapon's operation, they worked very well to motivate the relatively inexperienced crewmen involved. It also precluded much of the "mickey mouse game" stigma so often attributed to laboratory psychomotor tasks.

2. Training

As discussed in Volume 2, each monthly team of 7 crewmen arrived 4 days prior to the formal motion tests in order to train on the various tasks and to be briefly (5 minutes each) exposed to SS 3, 4, and 5 in a 15-minute "sampler" run. After being introduced to each task, the crewmen practiced it at least twice (generally several trials per session), and those who had trouble were generally given extra practice. Thus, each of the four primary crew members was trained in any given task, although not always to an asymptotic level of performance (this would have taken a prohibitive amount of time).

Anticipating further improvement in performance towards an asymptote, we ran a series of static runs between each motion run from which the likely static trend could be inferred, such that the effects of motion could be separated from the effects of basic learning, at least for first-order effects (differential learning rates under motion were not accounted for).

Another fact known a priori from the Phases I and IA tests was that individuals vary widely in their asymptotic psychomotor performance, at least on most of the tasks employed here. To more sharply define the effects of motion, we planned to use subjects as their own controls wherever this stratification was extreme; that is, the effects of motion would be compared with nearly static runs for each subject. There is a valid counter-argument that says, "In an operational SES, a wide range of crewmen may operate any given task; therefore differences due to motion should be judged against the intrinsic variability of static task performance across all crewmen." Both points of view have been employed in the data analysis, where so noted.

3. Arrangement of Test Devices in Cab

To give an overview of the general arrangement of the cab environment in which the two crewmen lived and worked for up to two days at a time [with one day off between (static or motion) runs] and to illustrate the location of the test devices within that cab, Fig. II-1 has been prepared.

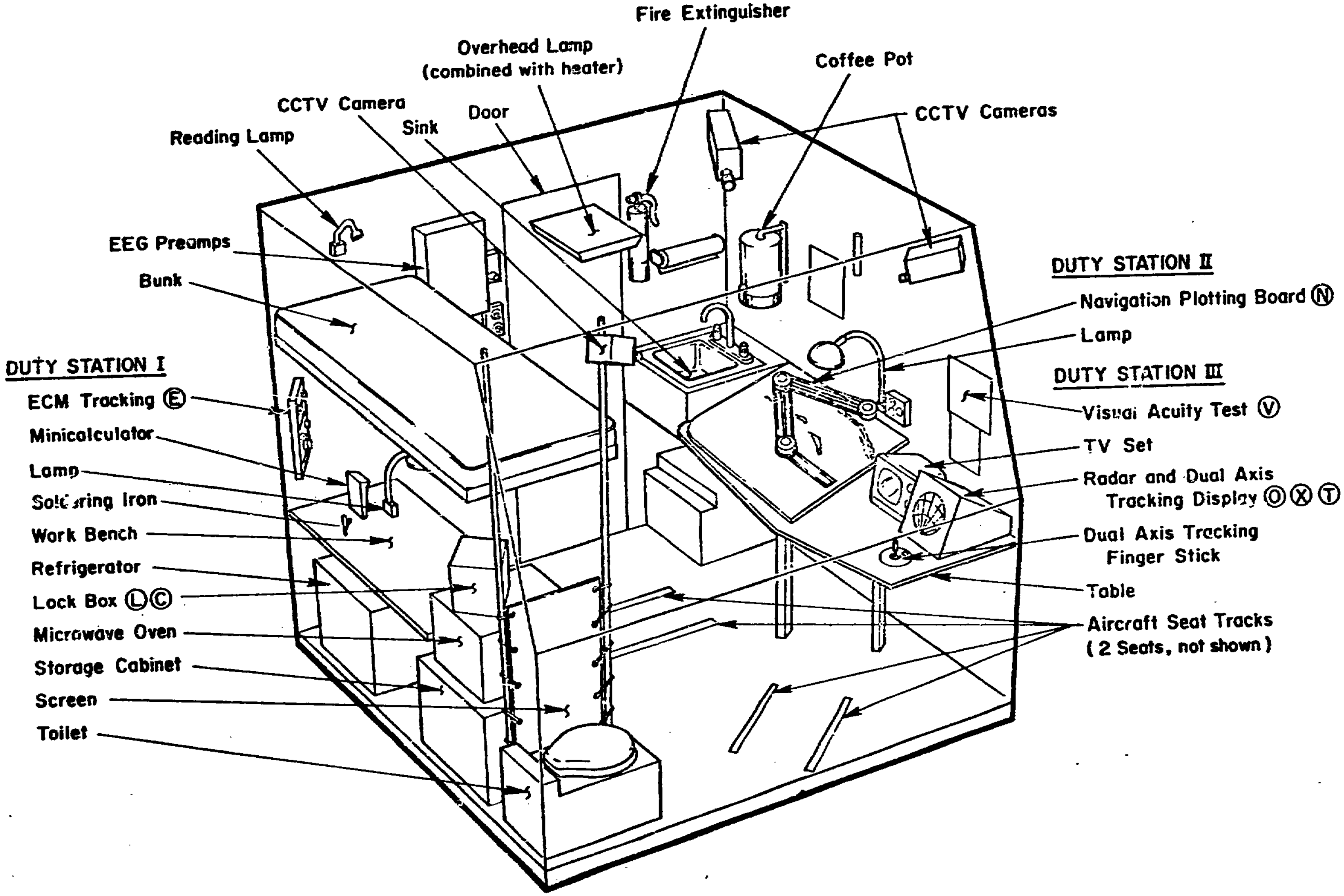


Figure II-1. General Arrangement of Apparatus in Cabin for Phase II

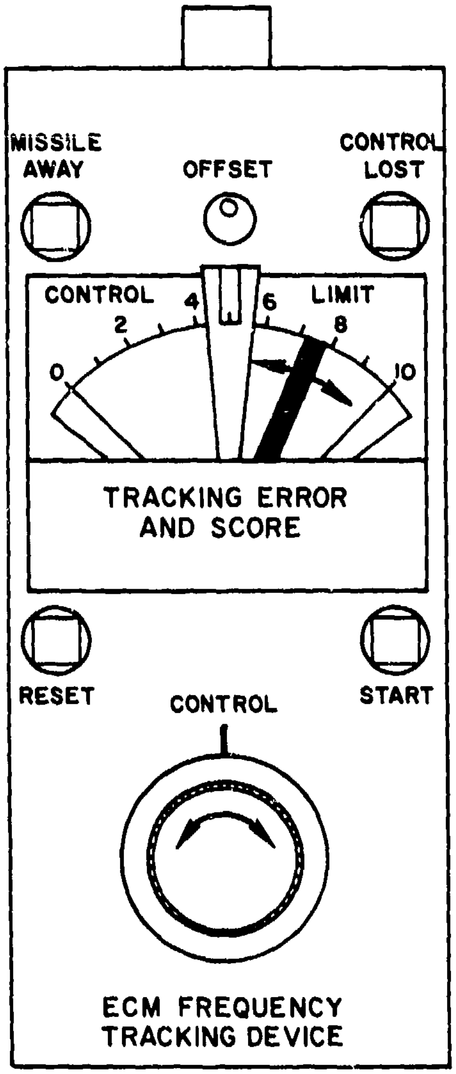
Notice that while one crewman slept in the upper bunk (for one 8-hour period per day), the other had unlimited access throughout most of the cab. While both were awake (two 4-hour periods per day), the space available for each was limited and required cooperation to pass, exchange seats, etc. The test apparatus was distributed throughout the cab, to permit simultaneous tests on different tasks by both crewmen. Further details on schedules are given in Volume 2 (Ref. 20).

B. ELECTRONIC COUNTERMEASURE (ECM) TRACKING TASK

1. Rationale and Approach

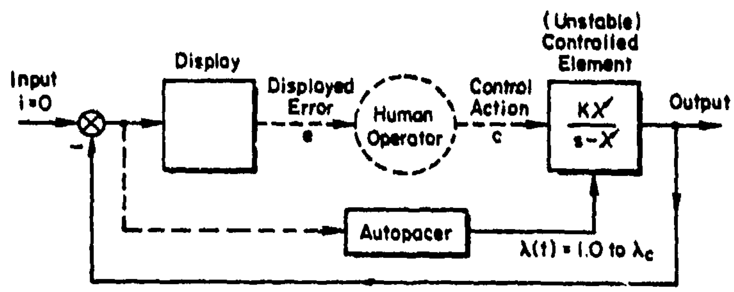
The main objective of this ECM task is to determine the effects of simulated SES motions on the ability of a crewman to perform precise, continuous tuning tasks of the type involving knobs and dials.

The task is based on the STI "Critical Instability Task" (or "Critical Task," for short) which was used in the prior MSFC simulation (Ref. 2), the Phases I and IA tests (Ref. 6), and, in other forms, in numerous other studies (e.g., Refs. 13-15). A special scenario appropriate to the SES missions, that of an ECM operator attempting to null out the frequency of an approaching cruise missile's radar despite changes therein, is used to motivate the crewmen. The task requires centering a needle on a dial via compensatory corrections of a freely turning knob underneath (see Fig. II-2). To simulate a "worst case" installation, it is operated with arm outstretched and unbraced. The controlled element dynamics are those of a first-order instability, which tends to diverge the needle off scale unless corrected continuously for the inadvertent inputs of the operator. The degree of instability (λ) is monotonically increased at a decelerating rate by an "autopacer" (allegedly simulating increasingly closer enemy range). The operator attempts to "hold lock" by keeping the needle centered as long as possible, typically 20-30 sec. At some intermediate range (i.e., at $\lambda = 3$) an anti-missile "MISSILE AWAY" light comes on to let the operator know he is performing well. Eventually, control by the operator is lost; this determines the "CONTROL LIMIT" score (Critical Instability), designated λ_c. This endpoint is remarkably consistent for a given motion condition and operator, with the standard deviation being only 5-10 percent of the mean value, over several trials.



a) Front Panel of Remote Unit (Moving Subject's)

b) Operating the Moving Cab Unit



c) Block Diagram

Figure II-2. ECM-Tracking Task

Extensive background research, e.g., Refs. 13 and 14, has shown that the λ_c score correlates highly with visual-motor bandwidth and depends primarily on the same factors as does well-practiced performance in precise control tasks (i.e., visual-motor delays, stability margins, operator "remnant" noise, and biodynamic interference with visual and control activities). High λ_c scores indicate high operator bandwidth and, hence, better potential performance in such tasks. Five-trial runs are employed, a procedure that prevents the occasional aborted trials from unfairly biasing the score, and the entire test takes only a few minutes.

2. Apparatus

The apparatus was a special modification of the STI Mk VIII Critical Task Tester (CTT) which was used in the previous SES simulations. The basic Mk VIII unit served as the master computer and control box, and was located at eye height above the workbench in the northwest corner of the Static Cab. For the Moving Cab a lighter remote unit, containing only the display dial, control knob, and status switches and lights (Figs. II-2a) was installed in a similar location. The static operator switched functions to the moving cab whenever the static cab unit was not in use. No malfunctions occurred in this equipment during its 3-4 month period of constant use in a vibrational motion environment.

While seated at the workbench, the operator turned his head and torso about 40 deg to operate the CTT, with his arm in midair (unbraced). The unit was about 24 ± 4 inches from the operator's eyes, depending on his detailed posture. Although all subjects were instructed to "keep their hand unbraced" (i.e., on the knob only), it is likely that some crewmen braced their last two fingers on the instrument panel to reduce motion "feedthrough" (as shown, inadvertently, by the subject in Fig. II-2b who, incidentally had the highest λ_c score!). There was no way to control for this grip technique, so the data must be considered that of a random sample of crewmen operating wall-mounted knob/dial apparatus with typical grip techniques.

The terminal λ_c score was logged on an Operator's Data Sheet (Appendix A) by the experimenter from a digital voltmeter in the MoGen control room, while the subject received immediate feedback as to his score when the needle jumped to this score on the dial at the end of the run. The median score was noted (by inspection) and was relayed to the crewman by the experimenter.

3. Procedures

Subjects were trained on the ECM tracking task during the week prior to the start of formal tests. Experience has shown that about 5-10 dozen trials, distributed over a few days, are required to reach near-asymptotic performance. This was achieved for only a few subjects, while the rest showed residual learning, as will be shown later. It is important to note that the autopacer scheme employed in the CTT can (intentionally) result in either short or long runs for a given endpoint score, so time of trial is <u>not</u> a reliable indicator of score. This scheme prevents subjects from giving up prematurely near their limit. An incentive was provided in the form of a six-pack of beer of the subject's choice to be given (at the end of the test series) to each crewman who achieved a 5-trial median score of $\lambda_c = 5.0$ or more.

The exact procedure followed during each test is given in Fig. II-3 and need not be elaborated upon. The entire test takes 4-8 minutes.

The ECM Tracking test was administered once per day in the long runs, at about noon for the nighttime sleeper and at about midnight for the daytime sleeper. For the 6-hour runs the ECM task was administered twice, roughly within the first and last hours of each run.

As an overall comment, this task elicited good motivation from all crewmen, and relatively few premature aborts or problems were encountered. In a few cases, severely nauseated crewmen were unable to complete this (or any other psychomotor) task; these results are discussed later herein.

4. Results and Discussion

The mean score for the five trials was computed for each test. Although individual means for λ_c ranged from about 3.6 to 6.6 rad/sec, each subject's scores were quite consistent, the deviation being only $\sigma_{\lambda_c} = 0.46$ rad/sec or

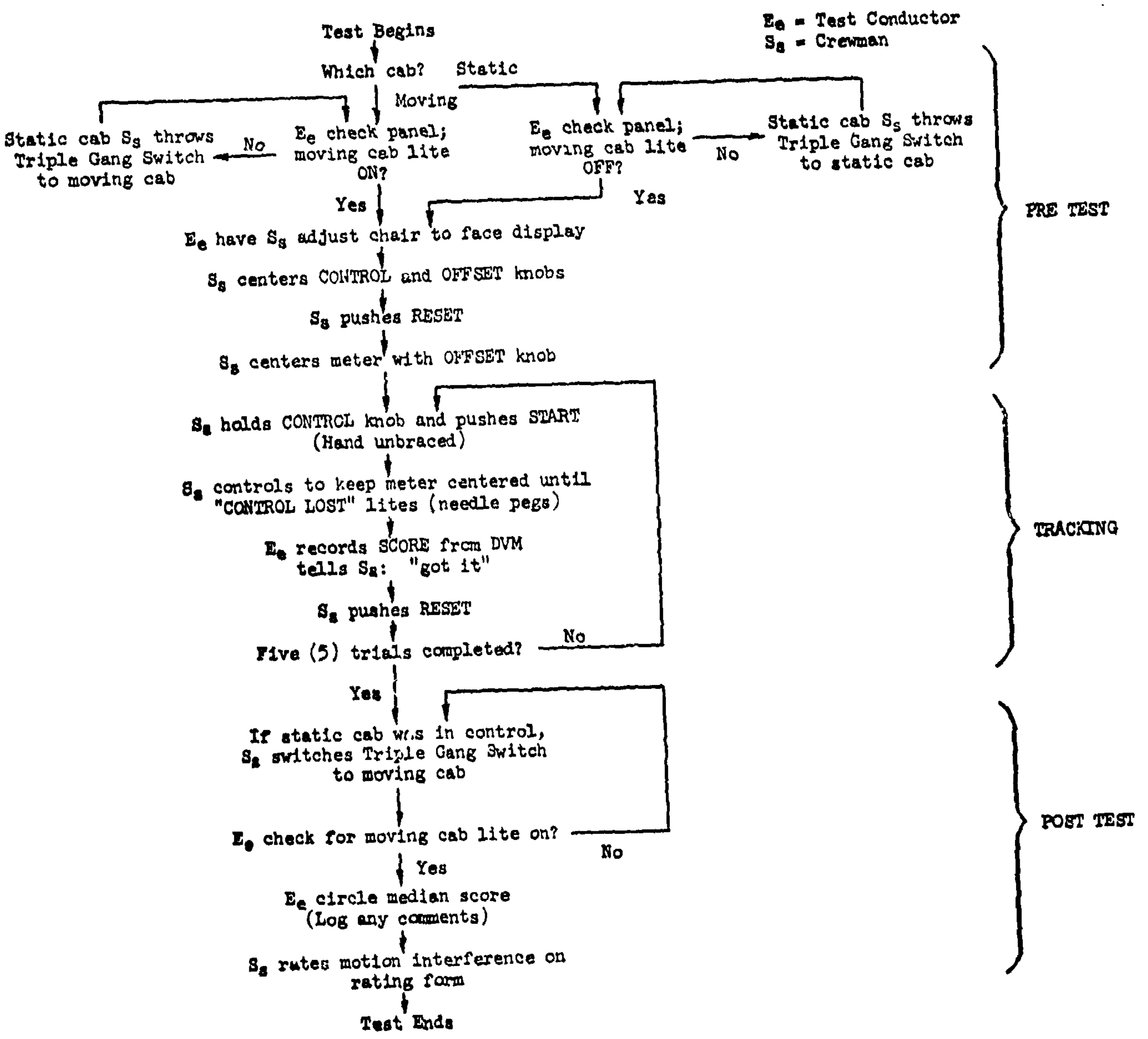


Figure II-3. ECM Tracking Task Procedure less than 10 percent of the mean. These levels and standard deviations of λ_c were typical of past experience and indicated the groups to be typical of any population of trained trackers.

Figure II-4 summarizes the reduced scores for all subjects and test conditions. In this figure (and in subsequent initial figures for various tasks), we present all of the key data for each of the six to nine grouped test conditions which varied significantly in motion waveform (i.e., sea state) and/or intensity (i.e., rms G_z) as shown in Table I-1. Because certain crewmen were consistently high or low and because each crewman did not receive all test conditions, this initial plot identifies each crewman by a separate symbol or letter (coded to his medical number, not his name) which is the same throughout this volume. To reveal learning trends, the abscissa of these "basic data" presentations is always the "Days from start of each subject's first formal test," ΔDay. For the majority of subjects ΔDay was obtained merely by subtracting the IRIG day of his first formal test from the IRIG Day and time logged on the Experimenter's data sheet. For two subjects, who returned in late September after previous sessions in August, their September ΔDays were obtained by subtracting an additional small time (13 days) to cause these later runs to follow contiguously their earlier runs without an excessive gap on the plot. This presentation allows the reader to judge for himself such matters as consistency within or between subjects, learning trends, and which subjects and conditions have the most complete or reliable data.

We have faired an eyeball-fitted "Likely Static Trend" line through all the static runs. Because asymptotic learning was generally involved, an exponential-type function was used for these fits, having the general form:

$$\text{Daily Score} \doteq \text{Asymptotic Score} - \text{Learning Increment} \cdot e^{-\Delta \text{Day}/T}$$

where T equals learning time constant (days). For the ECM scores, under static conditions, as shown in Fig. II-4:

$$\lambda_c = 5.5 - e^{-\Delta \text{Day}/3} \qquad (1)$$

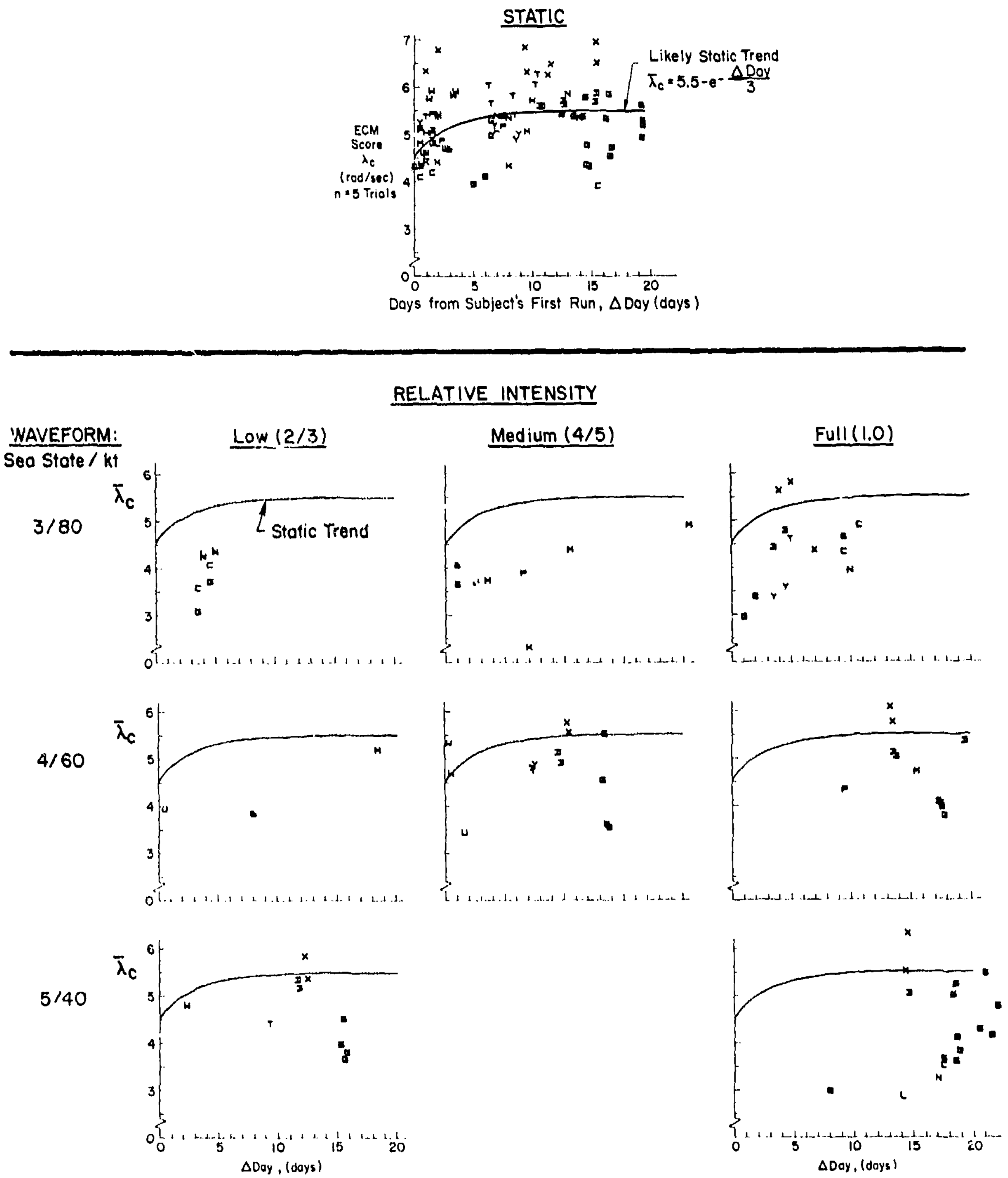


Figure II-4. Basic ECM Tracking Scores for Each Condition and Subject vs. Time From First

That is, the asymptotic mean score for some 20 subjects was 5.5 rad/sec with a learning time constant of about 3 days. As a practical matter, ECM scores were fairly stable after 3-5 days.

These basic data presentations show a few general points:

- Some learning was evident in most subjects, making it necessary to compare motion effects with the nearest static score.

- Some subjects score distinctly and consistently higher than others, making it necessary to compare groups of matched subjects between any given motion condition and either static or any other motion conditions. This restriction rendered impossible any overall statistical analysis, as no set of subjects experienced all conditions in Table I-2.

- The most subjects in any one motion condition "cell" was eight for the Full SS 3 and Medium SS 4 conditions; and of these eight, only six were the same.

- While most motion conditions show lower ECM scores than the "likely static trend," there is not a distinctive pattern of effects.

Several careful statistical analyses of ECM data among the various conditions were performed to more precisely define these qualitative observations and to consolidate the results. As noted in the foregoing list, the fact that each motion condition was not experienced by all subjects, coupled with the widely varying performance among individuals, made it impossible to easily compare group means for each condition. Instead, "matched groups" of subjects sharing a given group of conditions were analyzed in a series of limited Analyses of Variance (ANOV), each having the maximum number of subjects possible.

First, to validate the assumptions required for ANOV, the following facts were established:

- The distributions of trial-by-trial λ_c scores around the individual's mean value were all small and roughly Gaussian. The standard deviations were independent of the level of λ_c.

- Individual mean λ_c's were distributed fairly symmetrically and normally, but more widely, around the group's mean for a given condition. Thus, the λ_c scores need not be transformed for use in ANOV. (This had also been found in other experiments, e.g., Refs. 13-15.)

- No large or systematic differences were apparent between the first or second day's tests of a two-day run, or the early and late half test of a 6.5 hour run. So these could be treated simply as first test, second test to increase the data base.

In the following ANOV, the "Subjects" are considered as selected at random from an arbitrarily large population, "Conditions" are a designated subset of the eight possible ones, "Tests" are the ordered first or second of a run (as noted above), and "Replications" are the 5 trials within each ECM Test, considered as random samples. The powerful BMD-08V Generalized ANOV program was used here (Ref. 16). In about 12 percent of the cases, one of the two Test Period scores was missing; these were filled by simply replicating the available set of 5 trials for the other test period. Since test periods were always very close in λ_c anyway, this procedure had negligible effect on the results and permitted all of the data from other subjects to be employed. To contrast or compare motion effects on ECM scores most effectively, four separate analyses were made, as depicted in the sketch below.

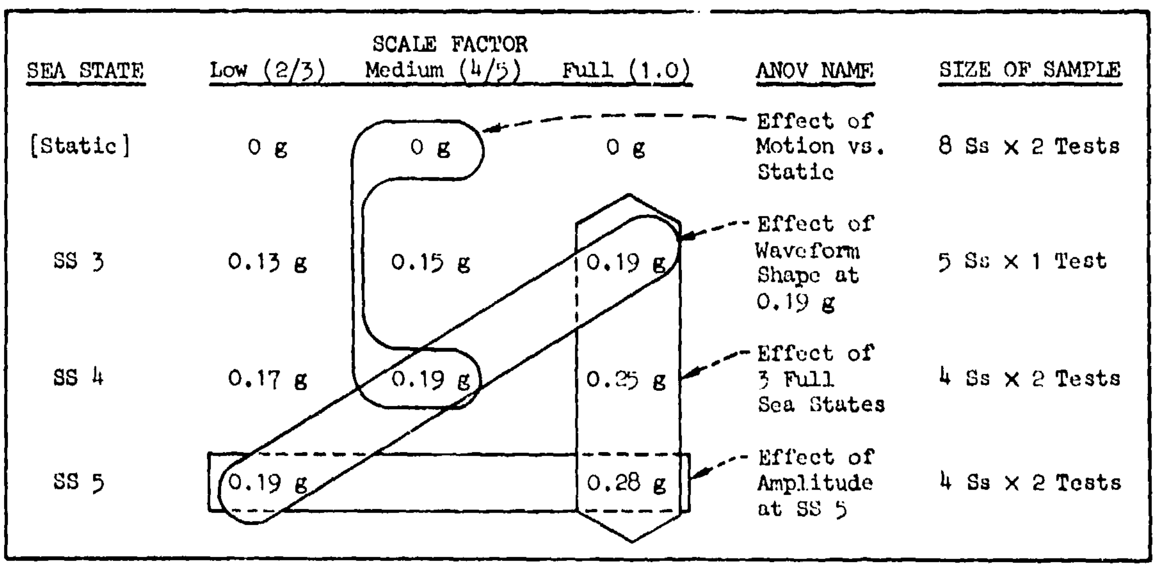


Figure II-5. Conditions Included in Various ANOV

The Low SS 3, Medium SS 3, and Low SS 4 cases were run in July, and experienced more erratic schedules, less training, and more dropouts than the August and September runs, hence they could not be formally analyzed with acceptable reliability.

A summary of the various ANOV results is given in Table II-2, which we will now discuss, along with relevant crossplots of the data. First, some general results from the ANOV (for all cases):

- The residual (trial-to-trial) variances in λ_c scores were small (typically $\sigma_{\lambda_c} < 0.5$ rad/sec) and consistent across subjects and conditions. Thus, the basic requirement of homoscedasity (equal variance) is met.
- Subjects varied from each other with individual means ranging from $\bar{\lambda}_c = 3.9$ to 6.1 rad/sec under comparable static conditions; and in all cases their stratification was highly significant ($p < 0.001 \equiv$ probability of such differences being due to chance alone). This fact has always been found for the Critical Instability Task, because λ_c scores represent measures of basic visual-motor properties which vary among individuals but are consistent within each one.

In two cases, there were significant interactions among Subjects × Conditions ($p < 0.01$), i.e., some subjects performed significantly different than others under various motion conditions. This, and some of the foregoing general statements above, is illustrated in Fig. II-6. It is apparent that most subjects have similar trends with motion in contrast to Subject 40, who is erratic and is the reason for the significant C × S interactions in the ANOV table. Nevertheless, closer inspection of Fig. II-6 reveals that the typical trend (e.g., of the bars denoting the across-subjects average) is itself anomalous compared to what would be expected on the basis of past results; the ECM Tracking scores actually <u>improved</u> slightly at the rougher sea states taken across the Sea State analysis, as well as the Amplitude with SS 5 waveform analysis! Closer inspection of static trends earlier in Fig. II-4 suggests that some of the improvement between the SS 3 condition (run early in each month, roughly around D-DAYS 4-10) and the SS 4, 5 conditions (run around D-DAY's 10-20) is due to the normal learning trend. The corresponding average static λ_c scores for the four subjects analyzed in Fig. II-6 have been added as ✕, to be compared with the solid bars. The differences between static and motion means for these subjects at SS 3, 4, and 5 and 2/3 SS 5 are $\Delta\lambda_c = -0.50, -0.86, -0.78$, and -0.81 rad/sec,

TABLE II-2. SUMMARY OF ANALYSIS OF VARIANCE FOR ECM SCORES

ANALYSIS OF: →		MOTION			SEA STATE			WAVE FORM			AMPLITUDE		
CONDITIONS →		SS 4A VS. STATIC			FULL SS 3, 4, 5			SS 3, 4A, 5A (0.19 G_z)			SS 5A (0.19g) VS. SS 5 (0.28g)		
SOURCE OF VARIATION	ERROR TERM	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO
Condition[1] (C)	C × S	1	23.87	53.83***	2	2.271	2.11 NS	2	0.0976	0.308 NS	1	1.741	1.68 NS
Subjects[2] (S)	R	7	10.26	40.29***	3	24.15	78.1***	4	10.46	49.2***	3	12.97	52.8***
Tests (T)[3]	S × T	1	0.049	0.085 NS	1	0.2430	3.41 NS	–	—	—	1	0.1805	0.737 NS
C × S	R	7	0.4435	1.74 NS	6	1.078	3.48**	8	0.317	1.49 NS	3	1.037	4.22**
C × T	C × S × T	1	0.0038	0.15 NS	2	0.4578	1.57 NS	–	—	—	1	0.1620	0.21 NS
S × T	R	7	0.5737	2.25*	3	0.07121	0.23 NS	–	—	—	3	0.2448	0.998 NS
C × S × T	R	7	0.2607	1.02 NS	6	0.2913	0.94 NS	–	—	—	3	0.7583	3.09*
Residual (R)	R	128	0. 2547		96	0.3094		60	0.2126		64	0.2454	
Residual Standard Deviation		σ_{λ_c} = 0.461 rad/sec			0.505 rad/sec			0.556 rad/sec			0.495 rad/sec		

Notes:
1. Conditions compared in each analysis are noted at top of column.
2. Subjects were maximum numbers common to all conditions in column; $N_s = DOF_s + 1$.
3. Tests were day 1 vs. day 2 for 48 hr runs; first 3 hr vs. second 3 hr for 6.5 hr runs.
4. Significance level: NS = Nonsignificant; * $\leq$ 0.05; ** $\leq$ 0.01; *** $\leq$ 0.001 probability due to chance.
5. The ANOV is a factorial mixed effects model with subject as random samples and conditions and tests as fixed treatments at five replications per test.

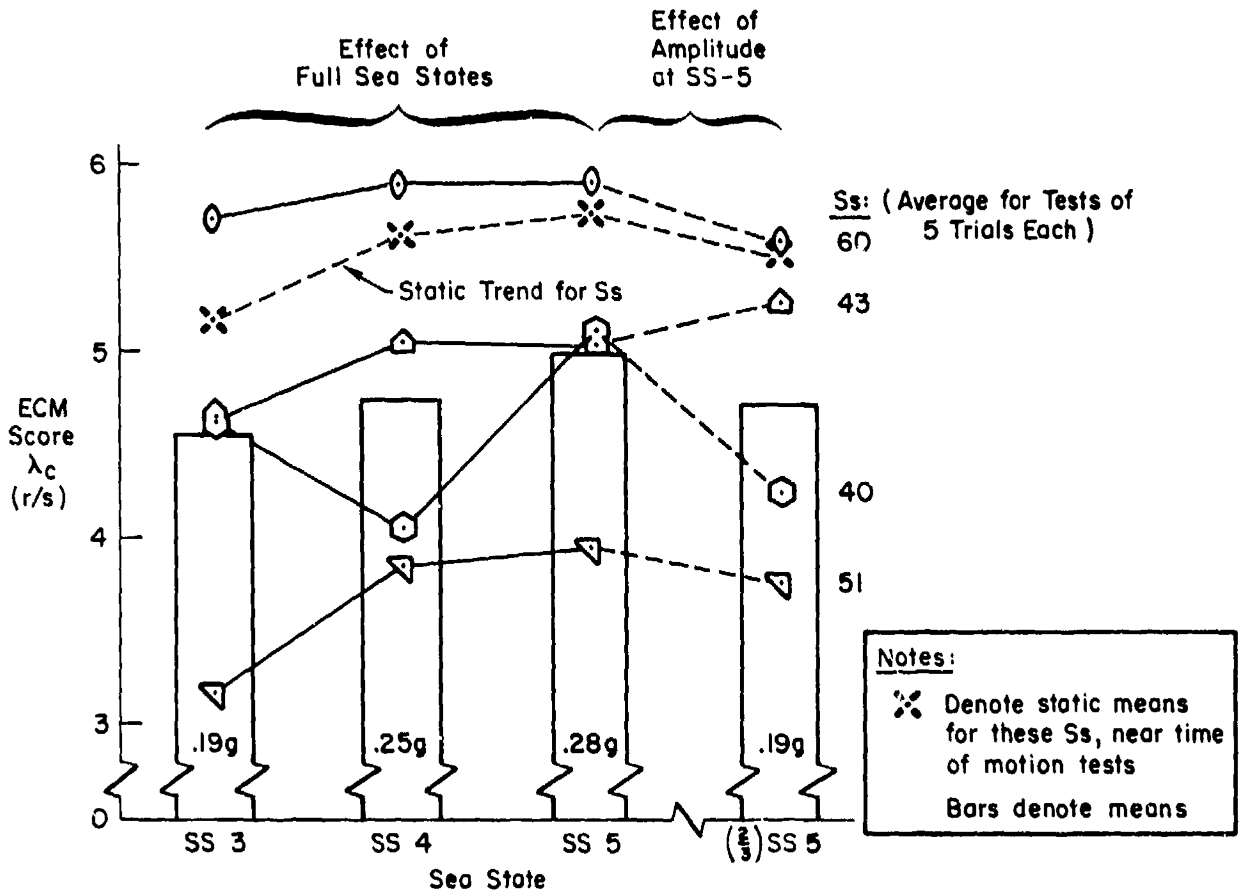


Figure II-6. Effects of Sea State and Amplitude on ECM Scores

respectively. This represents an ECM performance decrement of 10 percent at SS 3 and about 15 percent at each of the higher sea states, compared to static levels.

In any case, it is apparent that the differential effects of the three full sea states on λ_c scores are small, compared to the inter-individual effects, and this is borne out by the ANOV for Sea State, where the main effect of Condition is non-significant. The effects of full Sea State are confounded by simultaneous variations in rms amplitude and waveform, and it was hypothesized that SS 3 at 80 kt with 0.19 g rms might have more high-frequency effects on visual-motor tasks than the lower-frequency SS 5 at 40 kt, with 0.28 g rms. A sub-experiment was designed into the experimental design to run for 6 hr each the SS 4 and SS 5 waveforms attenuated to 0.19 G_z, same as the SS 3 case run for 2 days. Thus, the effects of spectral shape could be separated from the effects of amplitude. Only five subjects could be compared across all three conditions, at one test each. The results are shown in the ANOV summary under Shape, and in Fig. II-7b (lower left). There is absolutely no effect of the three spectral shapes at constant 0.19 g amplitude on the ECM task scores. Taken at face value Fig. II-7b indicates that reducing the SS 5 to 2/3 and SS 4 to 4/5 of their full amplitudes actually gives poorer scores than the full amplitude values. However, since the attenuated conditions were always given first, adaptation to the waveform could have improved the SS 4 and 5 performance.

Figure II-7c (lower right) shows the previously noted effects of amplitude at a constant waveform of SS 5/40 kt, here plotted vs. rms acceleration level. The same anaomalous trend of improved performance at higher accelerations is clearly evident, although not statistically significant (see Table II-2 under Amplitude).

Despite the apparent insensitivity of ECM performance to sea states or spectral shape within the 0.19-0.28 G_z range, there is a distinct and statistically very significant ($p < 0.001$) decrement of about 20 percent due to all motions (e.g., 4/5 SS 4) vs. static performance for a carefully matched set of 8 subjects with two test periods each. These results are plotted along with others in Fig. II-7a (top) versus rms g-level. The static means corresponding to the other groups of 4 or 5 subjects at the time of the motion runs are also shown on each plot of Fig. II-7, along with the residual standard deviation of λ_c, against which any mean differences should be evaluated. (Generally, differences smaller than the residual are non-significant, while differences much larger — as between static and motion *per se* — are significant.) The decrement of about $\Delta\lambda = 1$ rad/sec from a level of $\lambda = 5.5$ (static), i.e., about 20 percent, is generally observed.

It was noted earlier in this subsection that one or two of the best performing subjects were found *a posteriori* to have braced those fingers not holding the knob, under both static and motion conditions. If this was the reason for their improved general performance and resistance to

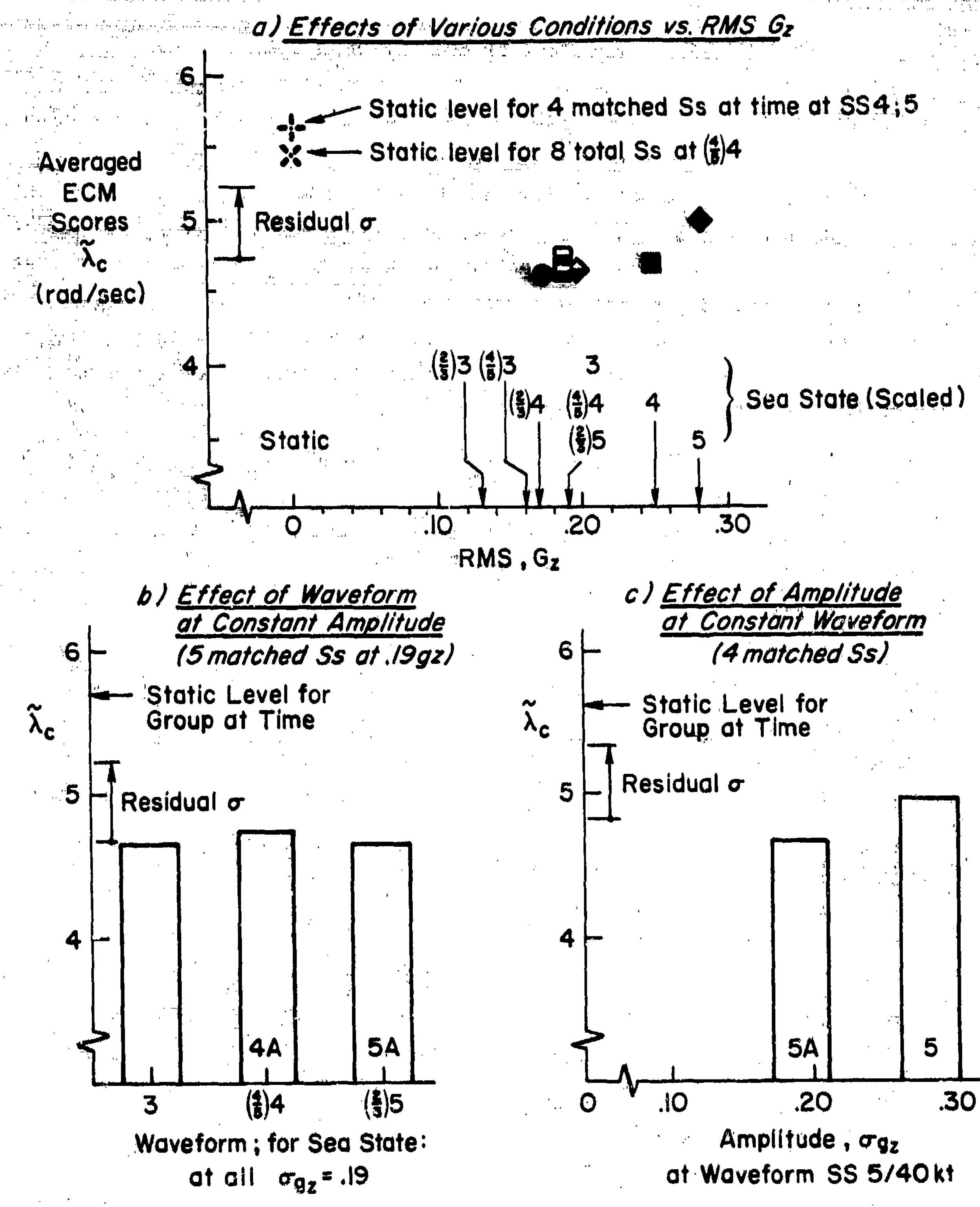


Figure II-7. Effects on ECM Scores from Various Sources motion effects, then it behooves equipment designers to provide a sufficient area around each such knob for optimum bracing of the hand and optimum knob control gain to avoid the need to change finger grips under normal knob movement situations.

During later comparisons between ECM tracking performance and Dual-Axis Tracking Task parameters, individual λ_c scores tended to correlate inversely with tracking errors and correlate directly with error characteristics frequency. These correlations are discussed later in Section II-C-4e.

The foregoing results apply to all subjects who performed the ECM task during static or motion conditions. However, some of these crewmen became motion sick early in the month at the SS 3/80 kt conditions, whereas earlier crewmen (in the MSFC and Phases I and IA programs) did not. In accord with ground rules of their participation, several subjects chose not to continue for a while, so their ECM data at subsequent conditions could not be obtained. Unfortunately, there is no good way to evaluate the significance of these lost subjects.

The nature of the ECM task (really, Critical Instability Task) is sufficiently demanding to marshal the attention of most operators even when they are distracted by malaise, and it is simple enough for a well-trained operator to complete even when he is debilitated. As a result, it was possible to obtain λ_c scores on eight subjects who were so motion sick that they aborted their runs soon after the tracking task. Their data are presented in Fig. II-8, using the closed symbol code of Table I-3. (These subjects are included in Fig. II-4.) Noted as subscripts are the subjective Kinetosis Ratings made as near as possible to the ECM Tracking test. The scores under severe kinetosis are plotted versus the corresponding average static scores, because a non-kinetosis motion score was not available. These data comprise a rare set of measured tracking performance made under severe (kinetosis) stress, and may deserve further analysis at some future date.

Two main points are indicated by these incipient-sickness cases:

- Some subjects were able to perform ECM tracking despite severe motion sickness to the point of retching while tracking. Performance dropped to about 50-60 percent of static scores when Kinetosis Ratings reached 6 ("Emesis").

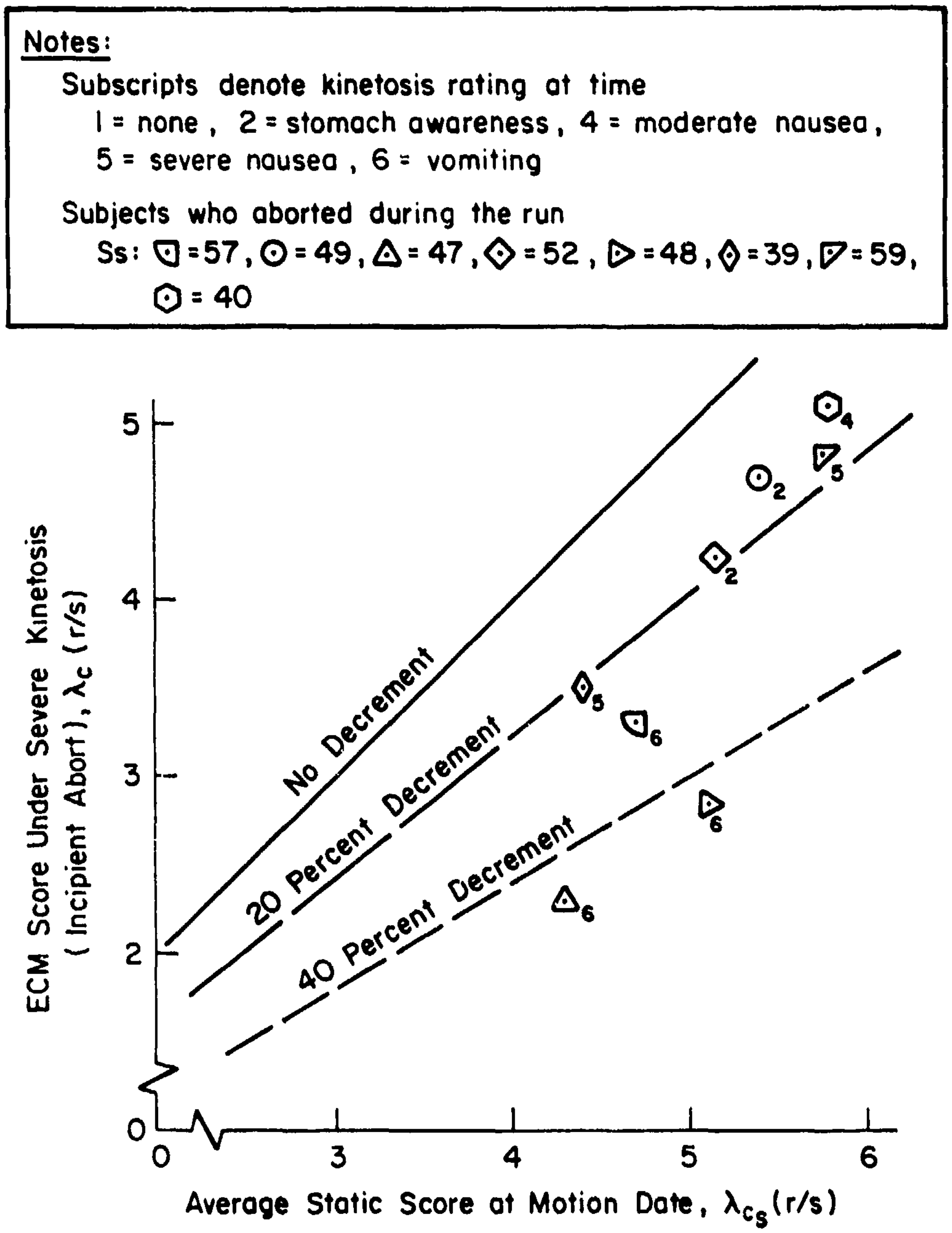


Figure II-8. ECM Scores for Subjects Who Aborted A Run Due to Severe Kinetosis

- Until Kinetosis Ratings dropped from 2 (Stomach Awareness) towards 5 (Severe Nausea), the decrement in performance was only about 20 percent, about the same as all other subjects who did not abort their runs due to kinetosis (but who may have felt nauseated).

These data provide evidence that critical-task tracking performance can be maintained at reasonable levels despite moderate kinetosis, and it will drop precipitously only when the operator nears his physiological limit.

5. Specific Findings and Conclusions

Our interpretation of the measured ECM Tracking performance under the various motion conditions is as follows.

a. At some small level of motion (on the order of 0.05 to 0.10 G_z rms), the performance of knob/dial tracking tasks begins to fall off towards a 15-20 percent decrement "plateau" at intermediate levels of acceleration (in the range from 0.15 to 0.30 G_z rms); regardless of the detailed spectrum as long as it has major power in the 1-3 Hz range.

b. With experience in a given sea state, most subjects gradually learn to cope with the motion disturbances and can bring performance up toward but not reach the static baseline level. Noting that the fitted "learning time constant" across all static runs was about three days, it is suggested that a similar time may be required to readapt to each new motion condition. However, the lack of any systematic effect of Day 1 versus Day 2 does not support this hypothesis.

c. An apparent anomalous performance trend, of improved ECM task performance at the higher sea states and amplitudes relative to lower sea states, was fairly consistent among the few subjects available for comparison, but may have been due to this readaptation-to-motion effect, even after each crewman's static performance asymptote had been reached. For example, Full Sea States 4 and 5 were always the last to be experienced, and they showed the highest scores under motion. This result has important implications on future experimental designs involving visual-motor tasks under motion conditions.

d. Differences among subjects are greater than decrements in ECM task performance due to the applied motions, and the better performers generally seemed to adapt more readily to motions. This conclusion suggests that high-performing crewmen should be used when motion conditions are severe, and implies further investigation of the hypothesis.

e. Eight crewmen out of twenty were sufficiently incapacitated by motion sickness as to be unable to continue their runs. ECM tests completed by them just before aborting their runs show that performance was maintained at levels typical of the motion condition until severe nausea and emesis (or retching) occurred, at which point it dropped to 50-60 percent of their static performance. This finding provides hard evidence that adequate performance on short but demanding tasks can be maintained despite moderate kinetosis.

f. Significant correlations between ECM Tracking scores and Dual-Axis Tracking task parameters were observed, and are described in the latter's section.

6. Recommendations

As in previous phases, the ECM Tracking task has proven easy to train for and to administer, precise and consistent in its measurement for a given individual, and reasonably sensitive to serious motion interference (either directly, as from inadvertent knob motions, or indirectly as from distraction due to severe kinetosis). As such, it should be retained in future habitability studies, as a common tie between all programs. Strong correlations with more complex tracking performance parameters (shown later herein) make λ_c a good compromise measurement, whenever a quick and easy test is required to measure potential tracking performance.

The sensitivity of scores to individual skill and to practice effects has two important implications in its use in future simulations:

- Individuals must be used as their own "controls," i.e., group means being compared must contain the same subjects.
- Frequent static tests must be made to determine the "likely static trend" for each subject.

Some controlled tests should be made to test the hypothesis, put earlier, that there is additional adaptation to each new motion condition (in terms of ECM tracking skill) with a few-day learning time constant.

C. DUAL-AXIS TRACKING

1. Rationale and Approach

a. Objectives

The prior task (ECM Tracking) tests the ability of crewmen to continuously adjust a knob and dial apparatus whose control grows more difficult with time, representative of an instrument which might be found at various electronic consoles. The Dual-Axis Tracking Task covers another important class of tracking tasks — those in which the crewman directs a reticle, sight, or weapon at some "target" using an azimuth-elevation display and a hand controller. A variety of error and control activity parameters were measured in hopes of providing diagnostic insight as to whether any observed changes in overall performance were primarily caused directly by motion interference with the display perception or whole-body motion "feedthrough" to the control stick or indirectly by increased fatigue or kinetosis (e.g., see Ref. 11)

Although this task did not attempt to mimic any particular weapon system, it is typical of several weapon tracking tasks which may be on an operational SES, such as: antiaircraft gun tracking with lead-computing sights; manual backups for laser, radar, or infrared tracking devices; operation of remotely aimed telescopes (used for sea, land, or air inspections); and tracking of Remote-Piloted-Vehicles during their prerecovery landing phase.

b. Approach

The scenario is that of a crewman providing manual backup tracking for a remotely located anti-aircraft gun or multiple-missile launcher. The crewman directs the weapon in elevation and azimuth by continuously attempting to center a pipper both horizontally and vertically on a CRT display using a single, two-axis finger stick (i.e., a compensatory tracking task). The centering "crosshairs" are fixed on the 9-inch CRT (but are drawn electronically to avoid parallax errors), while the target pipper (a "1.0 cm double-cross #) is steered to the center by compensatory movement of the finger stick (a right pipper requires a left control movement).* The duration of tracking is about two minutes, and the operator is instructed to "always keep as closely centered as possible to provide proper line-of-sight information to the weapon computer." Thus, high accuracy was stressed as the performance criterion.

The weapon's sighting device dynamics (controlled element) are represented by an adjustable first-order lag in series with a slightly-divergent first-order unstable element. The latter is used to allow the operator's inadvertent control motions ("remnant") to continuously disturb the system and thereby to avoid the need of a separate tracking input. This scheme has been used by STI with good success in a number of other simulation programs, including the MFSC SES simulation in which it was used in a speed control task (Ref. 2). As far as the operator is concerned, he is aware only of some lag and smoothing between his control actions and the pipper motion, and the fact that failure to control the pipper continuously results in the pipper being "lost" from his field of view. The absence of a separate forcing function makes the resulting error scores more sensitive to any motion feedthrough effects, as desired, but it also yields stronger idiosyncratic variations due to intrinsic skill differences among various operators.

The controlled-element dynamics (identical in both axes) are represented, in Laplace operator form, as:

$$Y_c(s) = \frac{\text{pipper motion}}{\text{control motion}} = \frac{K_c}{(T_1 s + 1)(-T_2 s + 1)} \qquad (2)$$

where

K_c = display/control gain; (cm on CRT/cm motion of stick top) = 5.0 cm/cm

T_1 = lag time constant (sec) adjustable from 0.1 to 10 sec

T_2 = the divergence time constant (sec) adjustable from 0.1 to 10 sec

*This control strategy, which is the opposite of steering a conventional sight centerline to the target, was used to match the strategy required on the ECM Tracking Task, thereby avoiding any negative transfer of training between the two tasks, which are performed by the same operator in (possibly) close time proximity. Furthermore, experience has shown that this scheme is easier for naive operators to learn quickly.

The values of the gain and lag time constants were optimized in pre-test trials to provide a challenging task in two axes under static and motion conditions, while not requiring excessive lead-equalization by the operator (which might cause mutual negative transfer between the ECM and weapon-tracking tasks). Two sets of values were used during the tests, one for the few days training period, and the other for final practice and formal testing, as shown in the controlled element transfer functions below:

		In Bode Format		In Root Format	
Training:	Y_c =	$\dfrac{5}{(0.1s + 1)(-1.0s + 1)}$	=	$\dfrac{-50}{(s + 10)(s - 1)}$	(3)
Testing:	Y_c =	$\dfrac{5}{(0.2s + 1)(-0.5s + 1)}$	=	$\dfrac{-50}{(s + 5)(s - 2)}$	(4)

Formal test values are such that the pipper will diverge off-scale within a second or so if not continuously and proportionally corrected. Thus the Dual Axis Tracking was quite demanding and sensitive to individual concentration, as well as motion disturbances.

By comparing, for each subject, the vertical vs. horizontal axis performance measures between static and moving conditions, the relative contributions of direct motion interference (predominantly vertical) and indirect motion effects in fatigue, remnant, etc. (predominantly horizontal) may be revealed. The upward-zero-crossing frequency of the error signals, $f^+_{o_e}$ (Hz), gives a measure of closed-loop visual-motor bandwidth, while that of the control signals, $f^+_{o_c}$ (Hz), reflects effects of direct motion feedthrough. An overall performance index is defined as the rms "vector" error (Root-Sum-Squared or RSS" of vertical and horizontal errors). Interpretation of these relatively simple measures may provide far more insight into SES motion effects on typical weapon tracking than might be gained from RSS error performance alone.

The interfaces have been designed to accept changes in future control sticks or display units, perhaps simulating specific weapon systems.

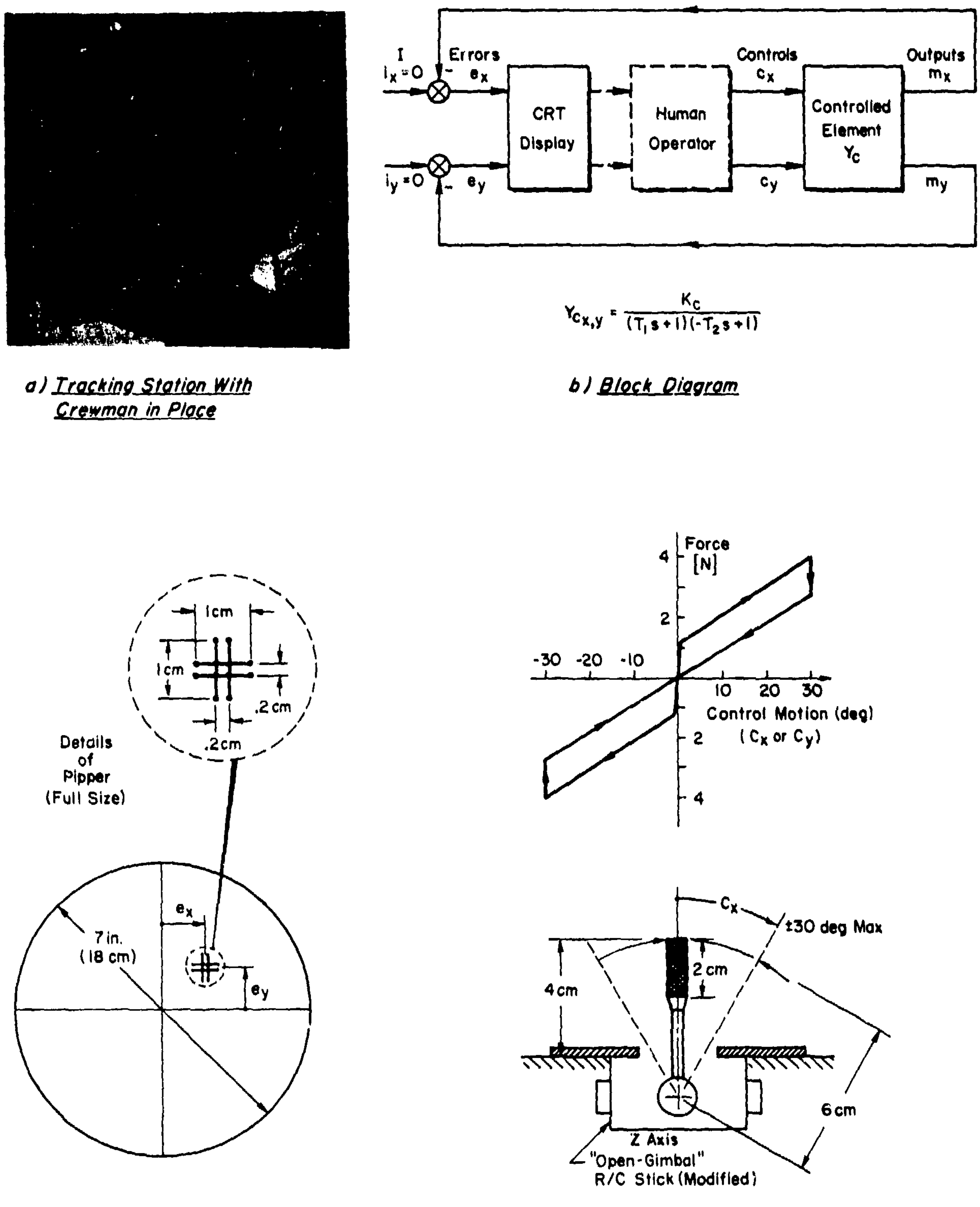
2. Apparatus

The tracking station was identical in each cabin and was located at the table used for the vigilance task near the southeast corner of the cabin. A photo of the cabin setup with a crewman in typical tracking posture is shown in Fig. II-9a. Only the CRT display, finger stick, and start button were located in the cabin; the task mechanization and scoring apparatus was in the MoGen control room.

The display was generated on the 9-inch CRT at more than a 1K Hz and 400 Hz refresh and computation rates, so no jitter was apparent. The CRT was typically about 30 cm from a subject's eyes and inclined so as to be roughly perpendicular to his line-of-sight. Because both the pipper and cross-hairs were electronically drawn on the CRT, there was no parallax error from view angle (which, otherwise, might have led to bias errors on the order of ±1 mm). As shown in Fig. II-9b, the pipper was a double-Greek-cross with pairs of arms 1.0 cm long and 0.2 cm apart and emphasized by dots at each intersection and end.

The finger control stick, shown in Fig. II-9c, was a modified radio-controlled-aircraft "open-gimbal" unit, whith additional springs for a stiffer force gradient but with preload reduced so as to barely assure centering of the stick when released. It was grasped by most subjects in the manner of a pencil, with arm in a diagonal (writing) position as shown in Fig. II-9a. Somewhat fortuitously, this finger-stick arrangement minimized any direct motion induced forearm-hand "feedthrough" to the stick compared with that from the larger, hand-gripped sticks sometimes used in weapon systems.

The controlled element dynamics and symbol generation were mechanized in hybrid form by HFR (program name: TRAK) using their REDCOR digital computer at a computation rate of 448 Hz. Various tracking error and control activities were computed on-line at 10 samples per second during the test interval. At the end of each run the computer calculated and printed out (on a teletype terminal) a summary of that run's data. That print out included the following data (23 items in all) for each trial:



a) *Tracking Station With Crewman in Place*

b) *Block Diagram*

c) *Details of CRT Display*

d) *Details of Control Stick*

Figure II-9. Dual-Axis Tracking Task, Setup and Displays

Subject Number, Run Number, Start Time (IRIG), Trial Time, Sample Time

Mean values of error and control in each axis: $\bar{e}_x$, $\bar{e}_y$, $\bar{c}_x$, $\bar{c}_y$

Root-mean-squared values of error and control in each axis: $e_{x_{rms}}$, $e_{y_{rms}}$, $c_{x_{rms}}$, $c_{y_{rms}}$

Standard deviations; $\sigma_{(\ )} = [(\ )^2_{rms} - (\bar{\ })^2]^{1/2}$: σ_{e_x}, σ_{e_y}, σ_{c_x}, σ_{c_y}

Overall Root-Sum-Squared; RSS = $\sigma_x^2 + \sigma_y^2$: e_{rss}, c_{rss}

Characteristic Frequency (of upward zero crossings): $f^o_{e_x}$, $f^o_{e_y}$, $f^o_{c_x}$, $f^o_{c_y}$

The computer also controlled the trial and sample (scored) time of each trial.

The reason for obtaining both rms values and standard deviations is that, in the event of an appreciable mean error (bias), the $(\ )_{rms}$ is a better measure of performance per se, while $\sigma_{(\ )}$ is a better measure of man-machine dynamic effects, say due to motion. As noted earlier, for a wideband input (here, simply the operator's remnant noise) the value of f^o_e is a measure of closed-loop man-machine bandwidth.

3. Procedures

a. Operations

The Dual Axis Tracking Task was performed once per day in tests of three trials lasting two minutes each. After the crewman is seated at the tracking station, the task is initiated and monitored via both a closed-circuit TV and a repeater CRT display in the Control Room by the Test Conductor. After the task is reset to initial conditions, the CRT displays the word "READY." When the subject wishes to start, he pushes a button just in front of the stick, which initiates the following computerized test sequence:

Time from Task Start	
−10 sec	Word "READY" goes off CRT and a 10 sec countdown marker starts to move down vertical axis
−10 to −5 sec	CRT displays the "HANDS OFF" for 5 sec during which subject releases stick to allow automatic zeroing of stick and error circuits

Time from Task Start

−5 to −0 sec	CRT displays "GRAB STICK," upon which subject grasps stick in a comfortable posture. Pipper remains centered on display
0 sec	Word goes off CRT and task begins
0 to 10 sec	Subject tracks target attempting to keep pipper accurately centered, but performance is not scored for 10 sec allowing operator to settle down into a stable tracking behavior
10 to 110 sec	Tracking performance is scored for 100 sec (time not signalled to subject)
110 to 120 sec	Task continues, unscored, to prevent "end spurt" effect in behavior or score
120 to 130 sec	Various scored parameters are computed and printed out on teletype in Control Room, and CRT is reset to "READY"

This trial sequence is repeated three times for each test. Should an operator lose control such that the pipper goes more than 1-inch off the CRT for more than a second, the trial is ended. If the scored time is over 50 sec at this point, the trial is accepted, but if the time is less than 50 sec, it is rerun. The actual scored time is used in all parameter averaging computations. The entire test takes about 15 minutes.

Scoring periods of 100 sec are used to insure a representative variety of acceleration waveforms to be experienced during each trial. During the month of July, the scoring period was inadvertently set to 10 rather than 100 sec. Despite the lack of sufficient time to get good averages, fairly consistent — albeit more variable — scores were obtained, so these were used for lack of better data.

b. Training

Crewmen trained for three to four days with progressively more difficult task difficulty. First they learned each axis separately, then both together. During early training the controlled element dynamics were:

$$Y_c = \frac{-50}{(s + 10)(s - 1)} \qquad (5)$$

in which a small lag of 1/10 = 0.1 sec is cascaded with a divergence time constant of 1/1 = 1.0 sec, a relatively easy level to stabilize once the operator got the knack of opposing a vector error (say, up-and-right pipper) with a compensatory control vector (here, down-and-left). When this technique became easy to a trainee, the controlled element dynamics were finally set to $Y_c = -50/(s + 5)(s - 2)$ in which a lag of 1/5 = 0.2 sec is cascaded with a divergence time constant of 1/2 = 0.5 sec. These dynamics are much harder to control, because the increased lag requires some lead equalization to avoid closed-loop instability, and the pipper can diverge off-scale in less than 1 sec if not carefully tracked. In the context of the scenario of manual backup control of a guided missile via an optical link, the operator's goal was to keep the error well within the ±1 cm span of the "fins" (pipper-cross; $\doteq$ 1 cm on the CRT) and, desirably, within the small 2 mm square of the "warhead." Only one subject could perform the latter, but most subjects could achieve the former performance criterion, at least under static conditions.

4. Results and Discussion

Following the same general pattern as in the preceding ECM-Task section, we will first present the complete set of basic performance scores, vector error, averaged over the three trials for each crewman vs. day from first test for each subject. They are grouped by condition, in order to reveal the intrinsic range of scores, temporal trends due to learning, and effects of motion, all in their least digested form.*

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*In accord with a joint decision among SESP, STI, HFR, and NAMRLD personnel to facilitate the interpretation of results among the several related reports, we are following a presentation/policy of plotting "better" performance upward and "worse" performance downward throughout this report. While this practice proved straightforward for the λ_c scores in the previous section, it does pose a problem for tracking error scores, which are intrinsically smaller when "better." Accordingly, we have used two conventions here: (a) "error" scores per se are plotted with increasing (worse) values downward; or (b) an "accuracy" metric, defined here as (error measure)$^{-1}$, is used where it proves appropriate.

a. Basic Vector Error Data

The basic vector error data are presented in Fig. II-10. The following general comments apply:

- The vector error is the root-sum-squared of the error standard deviations for each axis of control: $\sigma_e = (\sigma^2_{e_x} + \sigma^2_{e_y})^{1/2}$
- The number of crewmen tested at each condition varies widely. (The symbols are coded per Table I-3)
- After trying other possibilities, vector error data was plotted on log scales to better normalize the distribution of individual scores, which varied over an order-of-magnitude range
- The stratification between good and poor trackers tends to be preserved across time and conditions

Consider first the obvious temporal improvement in tracking scores for most crewmen due to continued learning of this complex skill. A typical (exponential) learning curve has been fitted through the median scores:

$$\sigma_{med} = .6 - .4e^{-\Delta Day/6}; \qquad (6)$$

$$\Delta Day = \text{days from first test of subject}$$

This reveals that there is roughly a 40 percent improvement between early and late (asymptotic) scores, with a "learning time constant" of about 6 days. This "likely static trend" line of median scores is repeated below in each motion condition as a reference for comparison of motion effects.

Considering the various motion conditions next, in the lower portion of Fig. II-10, it is apparent that the larger motions are accompanied by large losses in tracking performance for nearly every subject. For example, all 7 subjects tested in the full SS 3 condition showed an increase in error over their corresponding static runs, this averaging nearly a 50 percent increase across all the crewmen as tabulated in Table II-3.

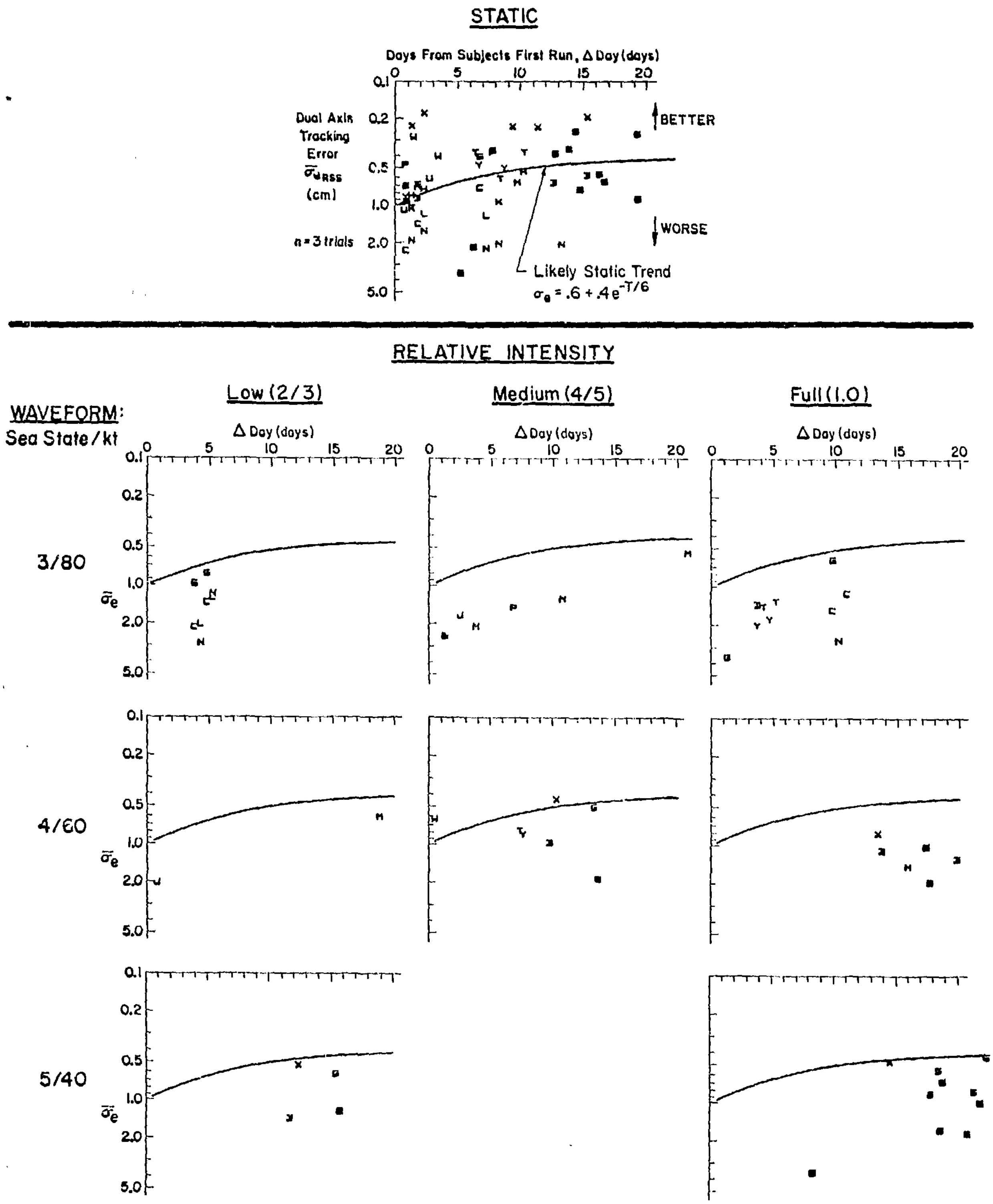


Figure II-10. Overall Performance on Dual Axis Tracking Task Versus Days From Subject's First Test, for Various Motion Conditions

TABLE II-3

VECTOR ERRORS FOR FULL SS 3 VS. STATIC CONDITIONS

SUBJECT NUMBER:	56	43	39	51	40	50	51		Avg.
σ_e (cm): Static	0.37	0.40	0.72	0.86	0.93	2.20	3.46	—	1.28
σ_e (cm): Full SS 3	1.43	0.61	1.51	2.02	1.38	2.63	3.53	—	1.87
Ratio: Motion/Static	3.86	1.53	2.10	2.53	1.48	1.20	1.02	—	1.46

The data in Fig. II-10 and Table II-3 also show that the motion induced changes in performance for a typical individual are usually within the static performance range of the worst trackers. Because of the wide differences in number of subjects per condition, non-normal distributions, and non-homogeneity of residual (trial-to-trial) variances, no parametric statistical analyses were made. However, all subjects showed some performance decrement under motion for most conditions (except low SS 3, where only 5 of 8 did), and a one tailed "Signs Test" for the direction of change verified this as a highly reliable conclusion, as summarized in Table II-4 below.

TABLE II-4

SIGNIFICANCE LEVEL OF SIGNS TEST FOR DECREMENTAL MOTION EFFECT

CONDITION COMPARED WITH STATIC	COMPARABLE CASES REPLICATION × Ss = CASES	NUMBER OF DECREMENTS	STATISTICAL SIGNIFICANCE LEVEL (ONE-TAILED SIGNS TEST)
Low (2/3) SS 3	2 × 4 = 8	5	NS
Full SS 3	1 × 7 = 7	7	0.8%
Medium (4/5) SS 4	1 × 7 = 7	7	0.8%
Full SS 4	1 × 5 = 5	5	3.1%
Low (2/3) SS 5	1 × 4 = 4	4	(< 5 cases; not valid)
Full SS 5	1 × 3 = 3	3	(< 5 cases; not valid)

b. Vertical vs. Horizontal Axes

To obtain more insight into the detailed causes of SES motion effect on such tracking tasks, other measures were analyzed and will be discussed next. It was originally expected that the vertical axes tracking measures would show more adverse effects than horizontal axes measures, because the cab motions were dominantly vertical. Such motions can affect the vertical tracking in two ways: (1) by direct biomechanical "feedthrough" from heave induced motions in the torso-arm-hand system (Ref. 11), and (2) from indirect visual interference due to impaired (or spurious) eye image motions due to heave induced head bobbing (Ref. 6).

In Fig. II-11 the vertical errors and control activity (averaged across all tested subjects) are plotted vs. the corresponding horizontal errors and control activity for various motion conditions. The change from the appropriate static donditions (unfilled symbols) to the motion case is shown by the dashed arrows. Several conclusions can be drawn from Fig. II-11:

- Both in motion and in static conditions, the vertical tracking errors are about 30 to 40 percent higher than the horizontal errors. The same is true of the corresponding control activity (standard deviation of control stick movements)

- The increments in errors and control activity due to each motion condition (length of dashed arrows) are similar in magnitude. The SS 3 errors are generally larger

- The close similarity between the error and control activity points in their static vs. motion trends for each condition implies that similar control gains were used in each motion condition by the typical operator

The lack of the expected increase in vertical control or error measures under motion can be explained by two observations:

1. The configuration of the finger stick, which required the hand to be placed over it with the forearm resting on the table halfway between the "down" and "right" directions, tended to preclude direct heave motion feedthrough and what there was of it went into both x and y axes

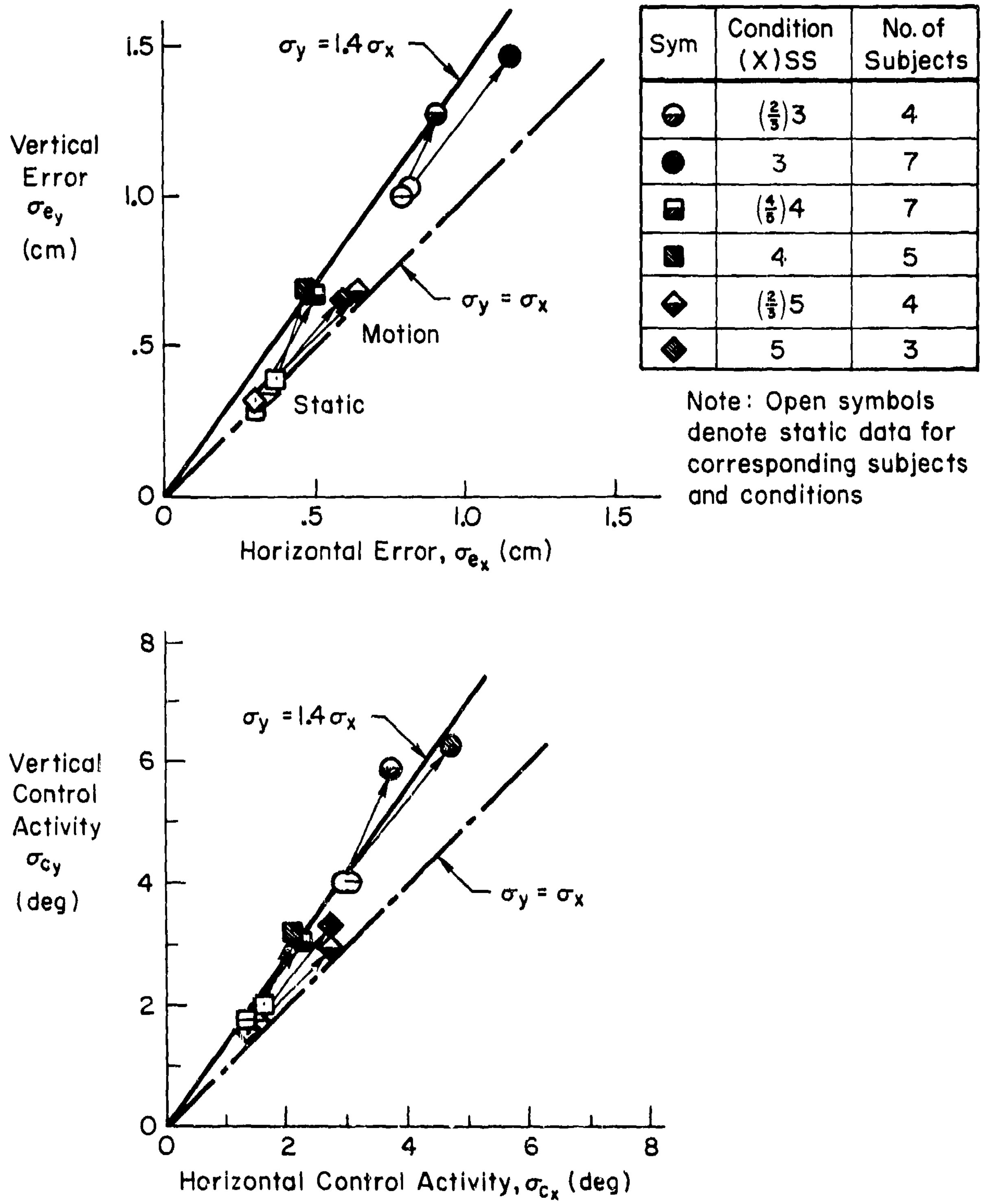


Figure II-11. Comparison of Averaged Vertical Versus Horizontal Errors and Control Motions at Various Conditions

2. Although vertical head bobbing was observed on the closed circuit TV, and it did affect fine visual acuity (Ref. 19), it apparently did not affect differentially (i.e., x more than y) the perception of errors between the 1 cm pipper and cross-hairs. Motion may have increased the perceptual "remnant" (error signal "noise") due to poorer resolution of the pipper under motion conditions. No one reported any difficulty in the visual tracking of the relatively large pipper/crosshair region with his eyes

Both of these tendencies would affect vertical and horizontal tracking axes similarly, thus masking any solely vertical effect due to heave motion. In hindsight, this tracking apparatus violated one of our task design criterion, i.e., that the configuration be a "worst likely case" in order to show sensitivity to motion if any was likely. Thus the results are not generalizable but apply only to tracking tasks having a finger stick, well braced arm, and large display format.

c. Tracking Accuracy vs. Frequency

Control and error characteristic (zero crossing) frequencies were originally taken in expectation of a differential vertical vs. horizontal effect due to heave induced feedthrough as explained above. For reason number 1 above, this was not observed, but an unexpectedly strong correlation between the error level σ_e and "characteristic frequency" f_o^+ (of upward zero crossings) was observed among various crewmen, as shown at the top of Fig. II-12. There is clearly a roughly hyperbolic relationship between σ_e (here, plotted worse = downward) and $f_{o_e}^+$. Call the inverse error = σ_e^{-1} the "accuracy," since it gets better when σ_e is smaller. Plotting σ_e^{-1} vs. $f_{o_e}^+$ should linearize such a hyperbolic relationship, as verified in the bottom half of Fig. II-12. The correlation coefficient, ρ, of this linearized relationship is around 0.8-0.9 indicating an excellent approximation by the least-squares best fit line shown:

$$\sigma_{e_x}^{-1} = 17.2 f_{oe_x} - 3.47 \; ; \; \rho = 0.88 \qquad (7)$$

$$\sigma_{e_y}^{-1} = 17.0 f_{oe_y} - 4.56 \; ; \; \rho = 0.82 \qquad (8)$$

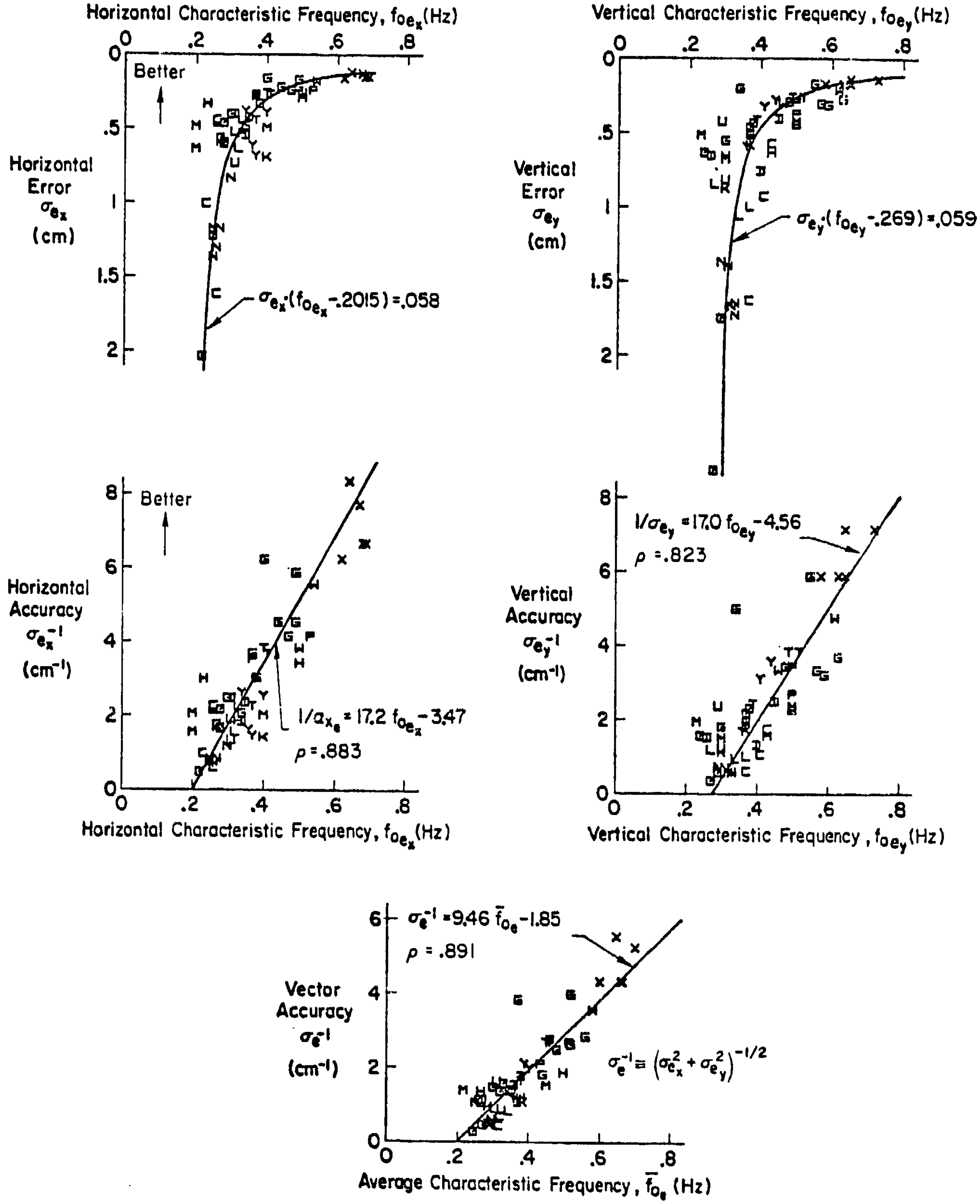


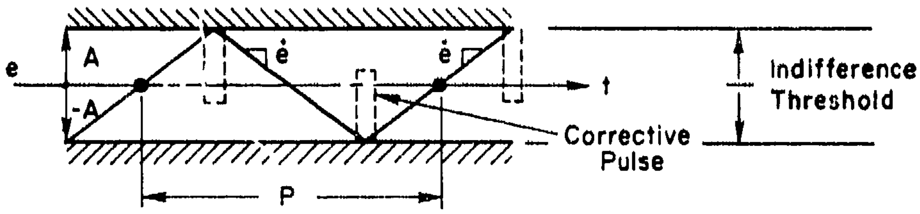
Figure II-12. Comparison of Correlations Between Performance and Frequency Parameters for Vertical and Horizontal Axes; Static Conditions

The corresponding hyperbolas have been put through the original data at the top of Fig. II-12:

$$\sigma_{e_x}(f_{o_{e_x}} - 0.20) = 0.058 \tag{9}$$

$$\sigma_{e_y}(f_{o_{e_y}} - 0.27) = 0.059 \tag{10}$$

After considerable unsuccessful analysis of this relationship (including a model of the spectrum resulting from wideband-perceptual-remnant, which is amplified by a low damped closed-loop mode of the man-machine system) a much simpler explanation finally evolved. This parabolic relationship is the result one would get for a limit cycling system having an "indifference threshold" of average double amplitude 2A wherein constant impulse corrections are made as soon as the threshold is exceeded, as sketched below.



$$\text{Amplitude:} \quad A = \frac{|\dot{e}|P}{4} \tag{11}$$

$$\text{Period:} \quad P = \frac{2(2A)}{|\dot{e}|} = \frac{4A}{|\dot{e}|} \tag{12}$$

$$\text{Frequency:} \quad f_o = \frac{1}{P} = \frac{|\dot{e}|}{4A} \tag{13}$$

$$\text{Average Absolute Error:} \quad |\overline{e}| = \frac{A}{2} = \frac{|\dot{e}|}{8f_o^{+}} \tag{14}$$

$$\text{RMS Error:} \quad \sigma_e = \frac{A}{\sqrt{3}} = \frac{|\dot{e}|}{4\sqrt{3}f_o^{+}} \doteq \frac{|\dot{e}|}{7f_o^{+}} \tag{15}$$

The last equation has the general hyberbolic form of the observed data, i.e:

$$\sigma_e \cdot f_o = \frac{|\dot{e}|}{7} = \text{constant} \tag{16}$$

In applying this concept to the Dual Axis Task results we make the following connections:

- The actual indifference thresholds are undoubtedly "fuzzy" leading to very uneven limit cycles, whose rms amplitude can be roughly equated to σ_e, above. Without time histories or amplitude distributions (none were made because the digital e signal was inaccessible for recording) this analogy cannot be proved.

- Instead of a constant slew rate, the Dual Axis Task has a somewhat divergent element, which, once redirected in the correct direction, tends to move ever faster until redirected again. The fairly strong detent action of the finger stick combined with appreciable friction requires a certain level of force to overcome, and once moved this combinations tends to put in a characteristic corrective "impulse." Such behavior fits the type of impulsive correction sketched above, thereby reinforcing the hypothesis. Since no time traces of control motion were recorded, this could not be directly verified for the data at hand.

- The largest static and motion errors and lowest frequencies were experienced early in each month (at the SS 3 conditions), and this is consistent with initially wider indifference thresholds which were closed down as experience improved.

- The net implication is that the limit cycle properties were dominant over normal closed-loop resonant mode properties, thereby creating a strong inverse correlation between axis crossing frequency and error scores. This reduces what can be deduced about motion effects on the operator's closed-loop bandwidth or remnant in the continuous tracking context.

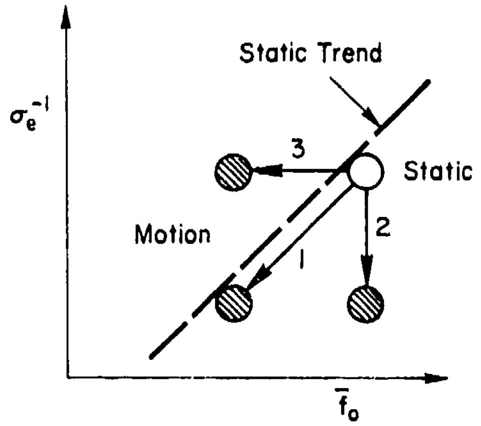
- The values of axis crossing frequency may be related additively to the operator's effective delay time, as well as his indifference threshold, so an increase in characteristic frequency <u>may also</u> reflect an improvement in the operator's potential <u>closed-loop</u> bandwidth, as well as improved (reduced) tolerances (Eq. 15).

- The vertical and the horizontal parameters are so similar, and their relationship so insensitive to motion condition, as noted previously, that the main effects of motion can be most simply represented by the "vector accuracy" $\sigma_e^{-1} = (\sigma_{e_x}^2 + \sigma_{e_y}^2)^{-1/2}$. Because σ_e is greater than either σ_{e_x} or σ_{e_y}, then σ_e^{-1} will be smaller than either one.

- The vertical and horizontal characteristic frequencies are similar, an average characteristic frequency $f_o^+ \equiv (f_{o_x}^+ + f_{o_y}^+) \div 2$ was computed. Vector accuracy is plotted vs. average characteristic frequency at the bottom of Fig. II-12. The best fit line through these static data (with an excellent correlation coefficient of 0.89) will be used next for comparing the effects of motion.

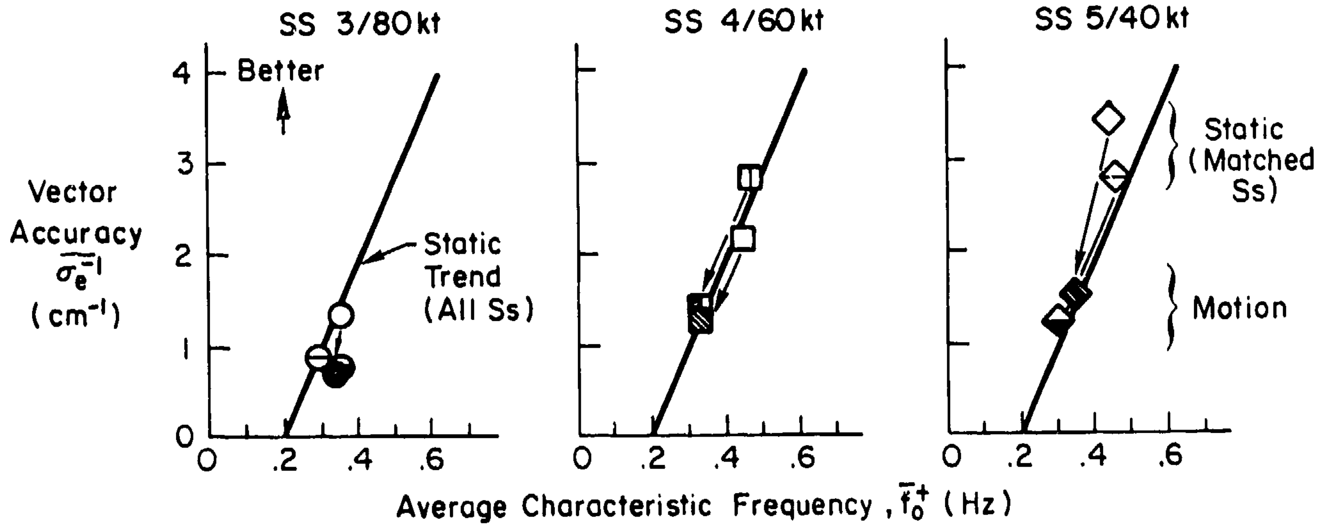
d. <u>Effects of Motion Conditions</u>

There are not enough points at any given motion condition with which to define a trend line and parameters, as was possible for the static case, so $\bar{\sigma}_e^{-1}$ and $\bar{f}_o$ were averaged for static vs. motion for matched pair (same subjects) data sets for a given condition. Based on the simple theory presented above, changes from the static cases can be interpreted with the following guidelines:

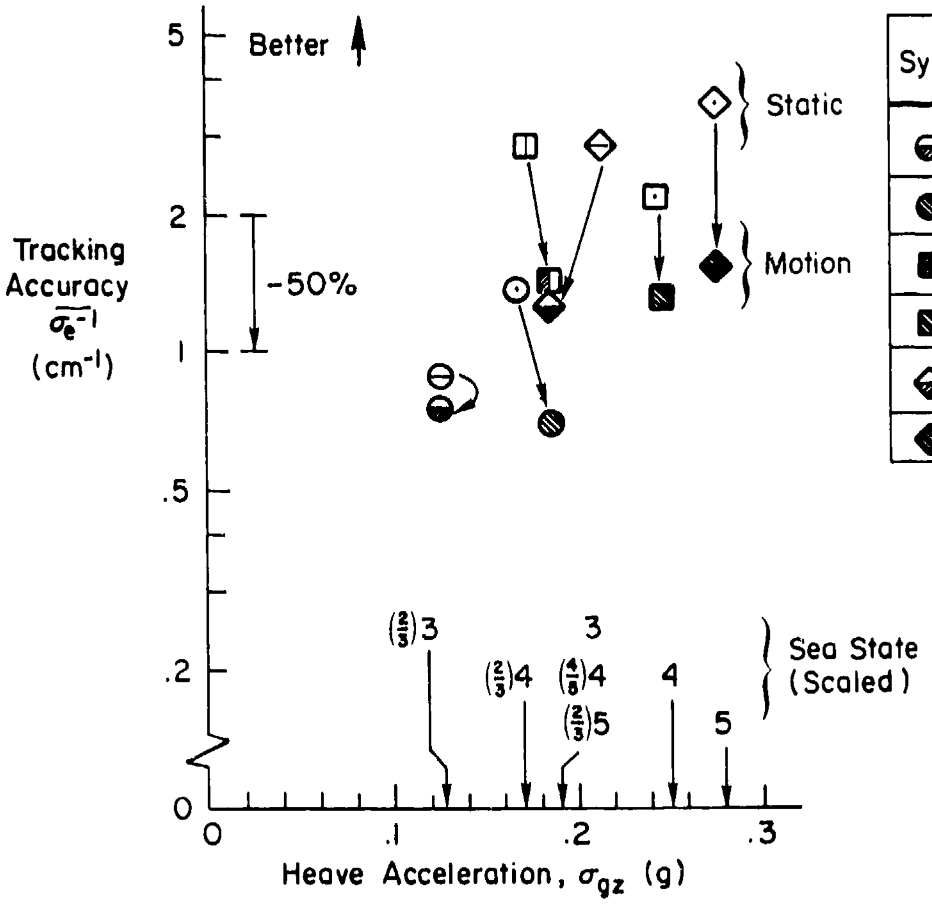


1. Same limit cycle family; wider tolerances due to less attention, etc.
2. Impaired perceptual process, or larger control pulses, or remnant
3. Reduced control pulses, longer delays

Motion effects on the Dual Axis Tracking parameters $\bar{\sigma}_e^{-1}$ and $\bar{f}_o$ are summarized in Fig. II-13. The top plots show the changes from corresponding static runs to each motion case. There is, in general, a decrease in accuracy and in frequency due to motion with the accuracy reducing slightly more than frequency relative to the static baseline trend. Since this is between effects 1 and 2 in the sketch above, it is probably due to larger control pulses and remnant effects, which is also consistent with Fig. II-11. The percent decrements in accuracy are tabulated in Table II-5 below.



a) Effect of Various Conditions on Tracking Accuracy and Bandwidth



Sym	Condition (X)SS	No. of Subjects
	$(\frac{2}{3})3$	4
	3	7
	$(\frac{4}{5})4$	7
	4	5
	$(\frac{2}{3})5$	4
	5	3

Notes: Open symbols denote static data for corresponding time and subjects. Shaded symbols denote motion cases.

$\overline{\sigma_e^{-1}} = \left|\sigma_{e_x}^2 + \sigma_{e_y}^2\right|^{-1/2}$

$\overline{f_0^+} = (f_{0e_x}^+ + f_{0e_y}^+) \div 2$

b) Correlation of Accuracy With RMS G_z

Figure II-13. Summary of Motion Effects on Dual-Axis Tracking Accuracy and Frequency

TABLE II-5

DECREMENTS IN AVERAGE VECTOR TRACKING ACCURACY
FOR VARIOUS MOTION CONDITIONS

CONDITION	LOW (2/3) SS 3	FULL SS 3	MED (4/5) SS 4	FULL SS 4	LOW (2/3) SS 5	FULL SS 5
NUMBER OF SUBJECTS:	4*	7	7	5	4	3
Accuracy: σ_e^{-1} (cm^{-1})						
Static	0.89	1.37	2.81	2.17	2.81	3.42
Motion	0.75	0.70	1.42	1.30	1.26	1.52
Decrement: (S − M)	0.14	0.67	1.39	0.87	1.55	1.90
% Decrement: = [(S − M)/S] × 100	16	49	49	40	55	56

*2 replications each

These decrements, which were shown earlier to be reliably consistent among various crewmen, run from 16 percent for low SS 3 to 56 percent for full SS 5.

The correlation of accuracy with condition is shown at the bottom of Fig. II-13, where σ_e^{-1} is plotted vs. the rms G_z level of the various motion conditions. It can be seen that the percentage change in accuracy is nearly the same for all conditions except low SS 3 while the absolute decrement is worst for full SS 5, representing a well practiced situation. Were this a true missile tracking situation, these losses in accuracy would increase by 3/2 the average miss distance (CEP, the circular error probability) over static conditions for the typical operator. The practical importance of the motion effects could then be assessed in terms of the measured CEP for static conditions relative to the required lethal miss distance.

e. Correlation with ECM Task Results

It was observed that crewmen with better ECM Task scores (λ_c) tended to have better tracking scores (σ_e^{-1}) and vice versa. This correlation between λ_c and tracking parameters σ_e^{-1} and f_o^+ is shown in Fig. II-14.

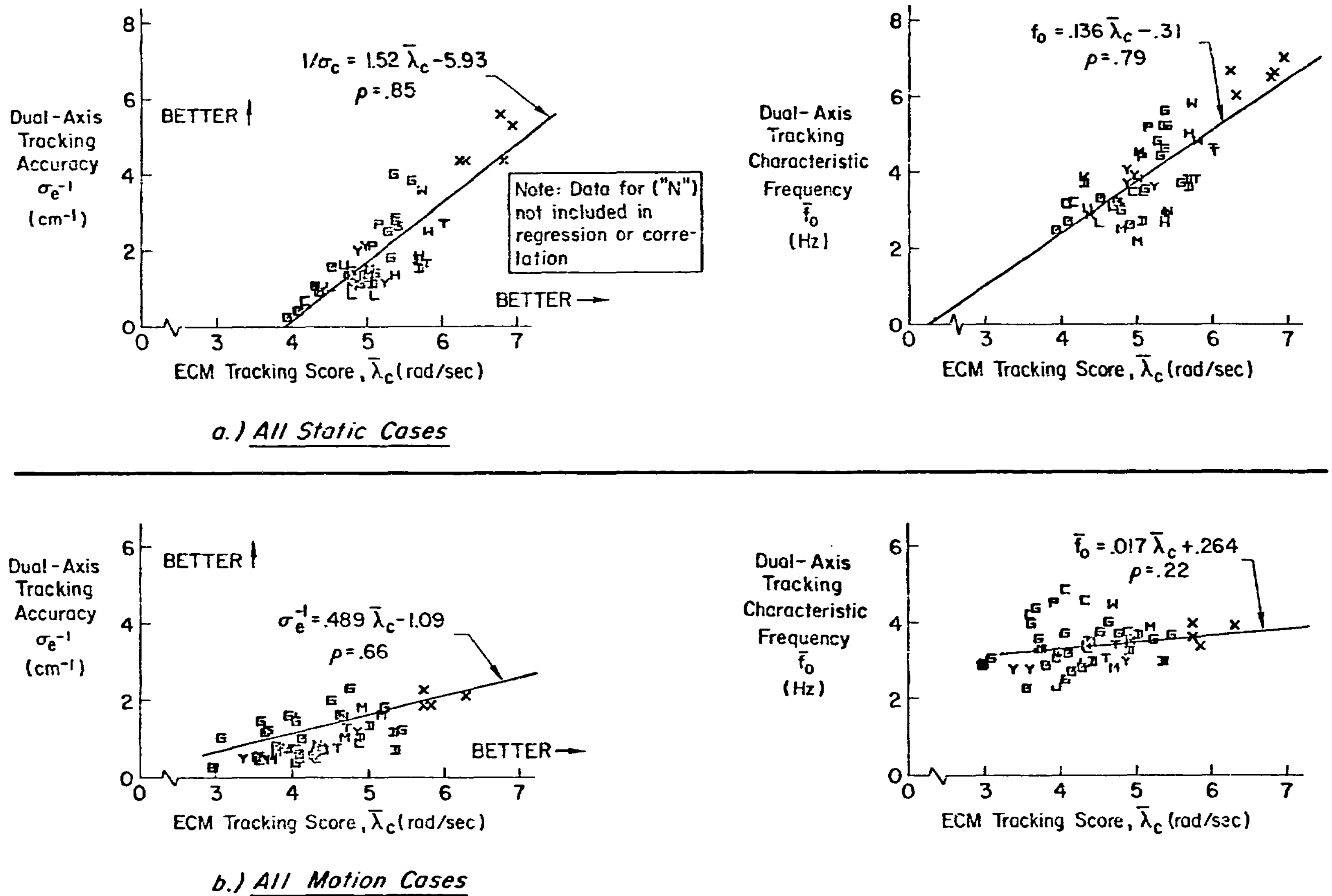


Figure II-14. Correlation of Dual-Axis Tracking Parameters with ECM Tracking Score

Subject 50 (symbol N) was omitted from these correlations as clearly atypical in his ECM vs. Tracking task behavior (i.e., reasonable and improving λ_c scores, but consistently and anomalously poor σ_e^{-1} scores).

There is a surprisingly good correlation (ρ = 0.80 – 0.85) among various crewmen between their static λ_c scores and tracking parameters. However, detailed inspection of the scatter plot for a given subject shows much less correlation tendency (given letters do not lie parallel to the trend line). This is partly due to different learning rates on the two tasks, the Dual Axis taking roughly twice as long as the ECM task to learn (as evidenced by the learning time constants of 6 and 3 days, respectively). Thus, while group scores of λ_c (a quick simple task) could be used to substitute for the more complex tracking measures, individual variations probably would not be so reliably predicted.

The bottom half of Fig. II-14 shows the correlations for all motion cases. Here the slope is much weaker and the correlation is much poorer for two main reasons: (1) the tracking accuracy dropped more than the ECM score, reducing the potential variation; (2) the variability in σ_e^{-1} scores was a much higher percentage of their mean, thereby reducing ρ. On the other hand, there is slightly more tendency for covariation of σ_e^{-1} and λ_c for a given individual under motion (e.g., see symbol G).

5. Specific Findings and Conclusions

The Dual Axis Tracking Task proved sensitive to motion conditions despite a wide range of individual skill levels. In nearly every case where matched static-motion comparison was made, all crewmen showed a decrement in tracking accuracy, σ_e^{-1}, relative to corresponding static runs. This decrement was only 16 percent at two-thirds SS 3, but jumped to 50-56 percent between two-thirds SS 4 through full SS 5.

A strong correlation (ρ = 0.8-0.9) between tracking accuracy, σ_e^{-1}, and characteristic frequency, f_o^+, was found across all static tests. The cause was analyzed as being a predominantly limit cycle mode of operation due to the high friction and detented finger stick and the absence of a strong external forcing function. Thus the diminished accuracy can be related to increased "perceptual indifference thresholds" and decreases in characteristic frequency to bigger perceptual motor delays and minimum increments of control. Evidence of both effects was found under most motion conditions.

Vertical tracking accuracy was roughly 40 percent worse than horizontal accuracy for all conditions, including most static cases. The absence of worse heave-induced-impairment of vertical with respect to horizontal tracking (as had been expected) is thought to be due to the arm-rested-on-table configuration of the finger/stick system (which suppressed direct biomechanical feedthrough from heave motion) and to the apparent lack of differential perceptibility of vertical vs. horizontal displayed errors (despite readily observed head bobbing). This finding is important in regard to weapon tracking.

Good correlation (ρ = 0.80-0.85) was found among various crewmen between Dual Axis Tracking accuracy or characteristic frequency parameters vs. the separate ECM Task scores run on the same day. However, variations within an individual over time or due to motion per se were not so well correlated, partly due to differential learning rates.

6. Recommendations

The Dual Axis Tracking Task was challenging, motivating, and relatively easy to learn for so complex a task. It can be used, with small improvements, in future habitability experiments. At least five to six days of distributed practice should be allowed to reach stable performance levels. To minimize limit cycle tendencies, the present finger stick with much friction (and thereby a large detent requirement) should be replaced by a low friction, nearly pure spring hand control stick of the type more common on Naval tracking consoles. A continuous quasi-random forcing function (with a bandwidth of about 1 rad/sec should be provided, either as a command or disturbance (retaining the compensatory display) in order to further mask and overshadow any residual limit cycle behavior.

In the future, time traces of both error and control in each axis must be recorded and analyzed, at least occasionally, during training and formal static and motion runs to permit assessment of the operator's behavior and training progress, and to facilitate data interpretation. Histograms of zero crossing periods and amplitude distributions would help greatly in task refinement and data analysis.

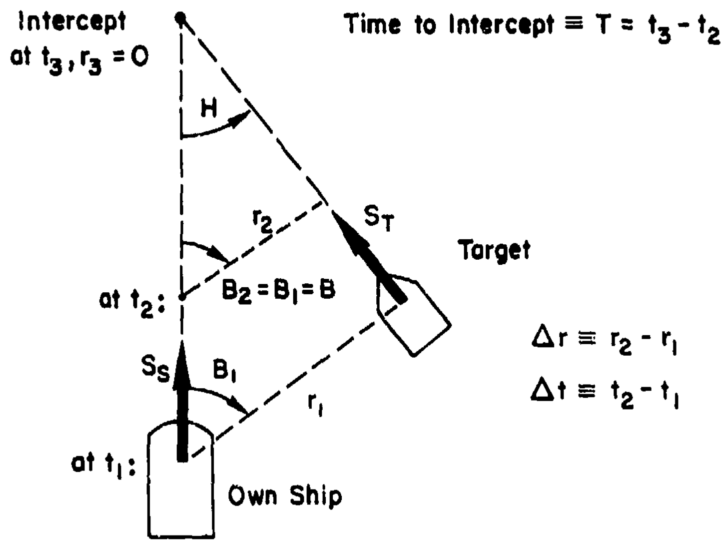
D. KEYBOARD TASK

1. Rationale and Approach

The Keyboard task is designed to test the motion sensitivity of keyboard operations such as might be typical of small onboard computers. It also contains components fundamental to a wide variety of data transmission tasks: verbal data transmission, transcription, and display readout. The task, in which the crewman's objective is rapid and accurate completion of a multi-step computational procedure, involves potentially motion-sensitive subtasks such as: listening to and logging multidigit numerals in a precise column on a form, reading these numerals, seeking and pushing proper keys on a wall-mounted computer, reading its small numerical replies, and writing these multidigit numerals in a small answer space. Numerous eye and head motions are required, as well as precise operations of the outstretched arm/hand and of writing.

The task scenario is that of determining the collision potential of an approaching "target." The crewman is told that radar is tracking a target (aircraft, missile, or ship) at constant bearing and decreasing range (i.e., a collision course). He is given the target's bearing and the ranges at two contact times, and his ship's speed on a partially filled out form. Using a wall-mounted minicalculator, he computes the time-to-intercept, the rate-of-closure, and the target speed and relative ship-to-target heading. The calculations required are summarized in Fig. II-15.

Task performance measures are: the time required to complete the keyboard computation, T_K; the number of errors (wrong answers per trial), N_E; and the number of restarts, N_R, i.e., times the computation had to be reinitiated due to recognized miskeying. The computation time and errors yield direct measures of motion effect on the speed and accuracy of keyboard operations. The number of restarts indicates whether an



Given: Range, r_1, at time, t_1; range, r_2, at time, t_2; ship's speed, S_S, and (constant) target relative bearing, B.

Find: Rate-of-closure, $\dot{R}$; time-to-intercept, T; target speed, S_T; and relative heading of target, H.

Units: Ranges in nautical miles; times in seconds, speeds in knots, and headings in degrees.

Formulas:

1. Closure Rate:

$$\dot{R} = 3600 \frac{r_1 - r_2}{t_1 - t_2} = 3600 \frac{\Delta r}{\Delta t} \quad \text{(kt)}$$

2. Time-to-Intercept:

$$T = \frac{r_2}{\dot{R}} = \frac{r_2}{\Delta r} \Delta t \quad \text{(sec)}$$

3. Target Speed:

$$S_T = [(S_S \sin B)^2 + (S_S \cos B - \dot{R})^2]^{1/2} \quad \text{(kt)}$$

4. Target's Heading:

$$H = A - B \text{ where } A = \tan^{-1} \frac{S_S \cos B - \dot{R}}{S_S \sin B} \quad \text{(deg)}$$

Figure II-15. Constant-Bearing Interception Problem and Formulas increment in computation time is the result of recognized processing errors which necessitate reinitiating the computation or greater deliberations which engenders slower processing speeds.

Subjective motion interference with the keyboard task is also rated on the Habitability Evaluation Questionnaire (see Subsection III-D).

2. Apparatus

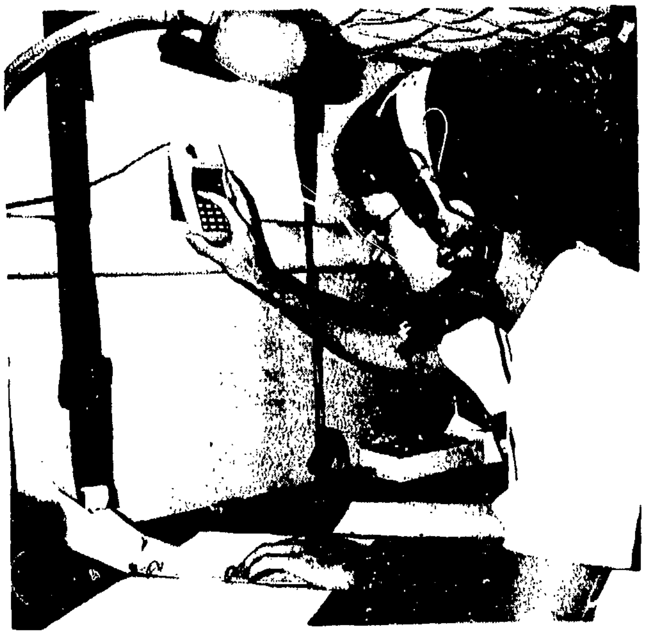
The apparatus included a Hewlett Packard HP-21 minicalculator in a HP security cradle mounted on the wall above the work bench (see cabin layout, Fig. II-1) at an angle of about 15 deg so that its display was approximately perpendicular to the subject's line of sight as shown in Fig. II-16. An instruction sheet with a sample calculation (see Fig. II-17) was kept in a looseleaf binder which was available for reference during performance of the task. The subject transcribed the given data and computational results onto a Keyboard Task Data Form (Fig. II-18). The Test Conductor timed the task with a stopwatch and logged and checked the crewman's transmitted answers against the correct ones (Fig. II-19).

3. Procedure

Subjects were given several training trials during three days prior to the start of formal testing, and as noted above, instructions for the keyboard entry procedure with a sample calculation superimposed were available during the task for ready reference.

The task was done in a three-problem "Test" administered in accordance with the procedure listed in Fig. II-20. Each of the three problems had a high-, medium-, and low-speed target arranged at random. Tests were given once per day during the long runs at about 0330 for the day sleeper and 1530 for the night sleeper. During the 6 hr runs, the test was done once, nominally 2 or 4 hours into the run depending on which of two work schedules a subject was on (see Volume 2 for details). For each test, the Test Conductor's forms (with preworked problems thereon) were selected at random from a group of such forms.

a) Subject Performing Keyboard Operation



b) Subject Reading Transcribed Inputs

Figure II-16. Keyboard Task Setup

Figure II-17

KEYBOARD TASK PROCEDURE FOR CREWMAN

Notes: 1. This procedure is specific to the HP-21 computer.
2. Values for sample calculation are shown under boxes, in displayed form.

1. Switch calculator power ON and mode DEG

Switch calculator power ON	and mode DEG	
0.00	0.00	

2. Set up calculator:

3600	$\boxed{\text{STD}}$	$\boxed{\text{DSP}}$ ·1	(Retains 1 decimal value)
3600.	3600.00	3600.0	

3. Record radar data on form as it is given by Test Conductor (and read back)

4. Enter range data:

r_2	$\boxed{\text{ENTER}\uparrow}$	r_1	$\boxed{\text{ENTER}\uparrow}$	t_2	$\boxed{\text{ENTER}\uparrow}$	t_1
3.3	3.3	4.6	4.6	190.	190.0	140.

5. Compute and record intercept data on form provided (see Fig. II-18):

$\boxed{-}$	(Record Δt)
50.0	50.0

$\boxed{R\downarrow}$	$\boxed{x \gtrless y}$	$\boxed{-}$	(Record Δr)
4.6	3.3	1.3	

$\boxed{x \gtrless y}$	$\boxed{\text{ENTER}\uparrow}$	$\boxed{R\downarrow}$	$\boxed{x \gtrless y}$	$\boxed{\div}$	$\boxed{\times}$	(Record T)
3.3	3.3	3.3	1.3	2.5	126.9	126.9

$\boxed{\div}$	$\boxed{\text{RCL}}$	$\boxed{\times}$	(Record $\dot{R}$)
2.600 −02	3600.0	93.6	93.6

6. Enter bearing and speed data

B	$\boxed{\text{ENTER}\uparrow}$	$\boxed{\text{ENTER}\uparrow}$	S_s
30.	30.0	30.0	72.

7. Compute target speed and relative heading

$\boxed{\text{BLUE}}$	$\boxed{x \gtrless y}$	$\boxed{R\downarrow}$	$\boxed{R\downarrow}$	$\boxed{R\downarrow}$	$\boxed{-}$	$\boxed{\text{BLUE}}$	$\boxed{\rightarrow P\uparrow}$	(Record S_T)
72.	62.4	36.	30.	93.6	−31.2	−31.	47.7	47.7

$\boxed{R\downarrow}$	$\boxed{x \gtrless y}$	$\boxed{-}$	(Record H)
131.0	3.0	101.0	101.0

8. Read data back to Test Conductor.
9. Repeat steps 3 through 8 for next case.
10. If you realize you've mis-keyed, go back to step 3 again; tell Conductor.
11. When finished, deposit your sheet in mailbox.

Figure II-18

KEYBOARD TASK DATA FORM FOR CREWMAN

Crewman ______________ Date ____________ Time of Day ____________

DATA GIVEN						CALCULATE				NUMBER OF RESTARTS
RANGES				BEARING	OWN SPEED	INTERCEPT TIME	INTERCEPT RATE	TARGET SPEED	REL. HEADING	
r_2 n. miles	r_1 n. miles	t_2 sec	t_1 sec	B deg	S_s kt	T sec	$\dot{R}$ kt	S_T kt	H deg	

KEYBOARD TASK DATA FORM FOR TEST CONDUCTOR

Crewman ______________ **Date** ____________ **Time of Day** ____________

DATA GIVEN						CALCULATE					
RANGES				BEARING	OWN SPEED	INTERCEPT TIME	INTERCEPT RATE	TARGET SPEED	REL. HEADING	NUMBER OF RESTARTS	TIME TO CALCULATE
r_2 n. miles	r_1 n. miles	t_2 sec	t_1 sec	B deg	S_s kt	T sec	$\dot{R}$ kt	S_T kt	H deg		sec
3.3	4.6	190.	140.	30.	72.	126.9	93.6	47.7	101.0		

Note: Conductor's form had precomputed data as above against which to evaluate crewman's errors.

Figure II-19. Sample Keyboard Test Data Form for Test Conductor with Sample Calculations

Figure II-20

KEYBOARD TASK PROCEDURE FOR TEST CONDUCTOR

1. Record date, time, and crewman's code on a Keyboard Test Data Form (KTD).

2. Read target ranges, times, target bearing and ship's speed listed on your KTD for trial 1 to crewman. After all are read, have crewman read back values; check these on your (KTD) form and identify and correct any errors; say "OK".

3. Say "GO," start stopwatch.

4. Crewman says "DONE," stop stopwatch, record task time, reset stopwatch.

5. Obtain from crewman the target intercept time, rate of closure, speed and relative heading, and check against precalculated answers listed on your KTD. (Do not tell subject if he is correct at this time.)

6. Repeat steps 2-5 for trials 2 and 3.

7. Ask crewman to note motion interference on his rating sheet under "Keyboard Tasks."

8. After the subject has completed all three trials:
   a. Tell crewman only "all answers were correct (or), in trial ___ (etc.), the ____________ was incorrect," etc.
   b. If similar errors appear in all three trials (indicating a common procedural error), tell the crewman "all three showed a similar error, please work through your sample problem to check your procedures."

9. Once per shift, collect each crewman's form, and staple it to pertinent Test Conductor's form.

4. Results

The mean computation time for three trials, $\overline{T}_K$, was calculated for each test as the basic measure of Keyboard task performance. Figure II-21 summarizes all mean computation times obtained for individual subjects; the data are grouped by motion condition as in Fig. II-4, the top plot showing all static data and those below the motion data for the eight different motion conditions simulated. Each motion data group should be compared with the "Static Baseline Trend" — an eyeball fit of a typical learning curve through median static computation times. (The T_K distributions are too skewed to be gaussian.) Also listed on each plot are the mean number of errors per trial ($\overline{N}_E$) and the mean number of restarts per trial ($\overline{N}_R$) for each test.

The Static Baseline Trend drawn in Fig. II-21 is described by the equation:

$$T_K = 80 + 45e^{-\Delta Day/8} \text{ (sec)} \tag{17}$$

indicating an asymptotic group average computation time of about 80 sec. The long learning time-constant, 8 days, indicates that some learning is still occurring at the end of the formal test periods, as is also borne out by the last scores of subjects 43 and 60 (symbols "G" and "X," respectively). Coupled with the relatively large learning increment (56 percent of the asymptotic level) and the inter-subject variability apparent on the plot (roughly a factor of two between highest and lowest score for the same ΔDay), this prolonged learning effect makes difficult the determination of motion effects, per se.

Comparison of each motion group of computation times with the Static Baseline Trend does not reveal any consistent pattern of motion effect; in fact, little if any motion effect is indicated (on a median basis). Two of the three low SS 4 data, which give the greatest indication of motion effect, belong to secondary subjects (46, symbol J, and 38, symbol B) (replacements who were still learning the task and therefore are not typified by the baseline trend). Comparison of the error and restart (N_e, N_R)

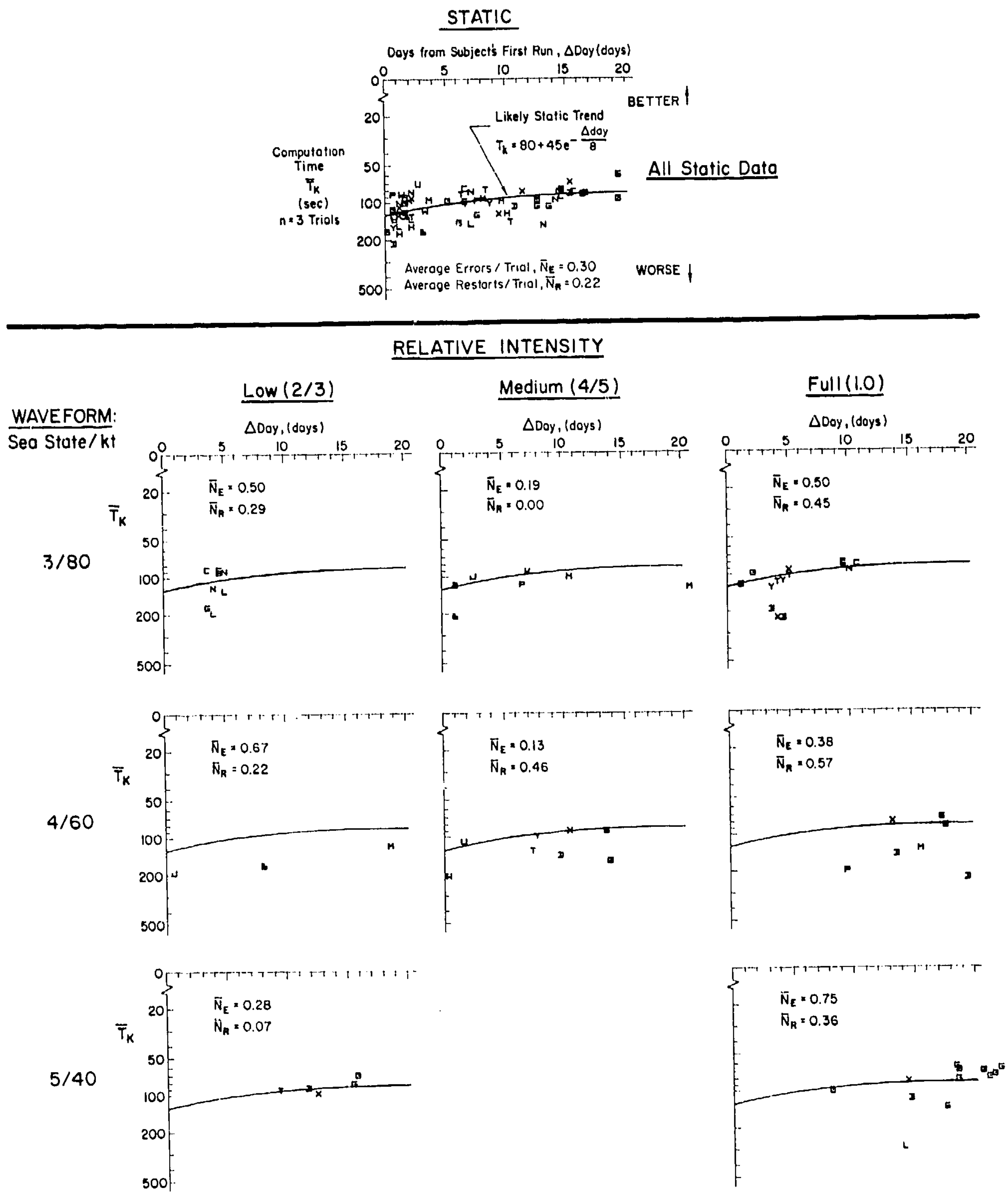


Figure II-21. Basic Keyboard Task Data for Each Subject vs. Time, Grouped by Test Condition averaged across the subjects on each plots also reveals an inconsistent pattern, which reflects the idiosyncratic individual and isolated nature of their occurrences.

From the foregoing discussion it is evident that if any motion effects are embedded in these data, they will be revealed only by a careful comparison of matched static and motion data for the same set of subjects. Such a comparison is presented in Table II-6, wherein performance data for medium and full SS 4 are compared with corresponding static data for eight and six different subjects (Subject 40 has two data points in the latter grouping), respectively. These two conditions were selected because they group a relatively substantial amount of data representing the performance of a fairly large number of different subjects, most of whom were primary (first-string) crewman, and because they were run during the last half of the formal test periods so that learning effects are less pronounced. Based on the ECM and Dual-Axis Tracking data analyses presented in the previous two sections, the absence of any pronounced indication of motion-induced Keyboard performance decrement in Fig. II-21, and the longer learning time constant and lesser consistency of the Keyboard data compared to the two Tracking task data sets, a comparison of differential effects across motion conditions would be fruitless. Thus, only the presence or absence of performance decrement due to any of the simulated motions is examined, and data for these two conditions are sufficient for that purpose.

Table II-6 lists average computation time, the errors and restarts per trial under motion, comparing these with the pre- and/or post-motion static run values of these parameters for the matched subject groups. Median computation times are also listed in the table since it was felt that these might be more representative of "typical" performance than the averaged values, as a consequence of the isolated nature of restarts which generally increase computation time by multiple increments and, thereby, unduly bias the average times. Errors and restarts per trial were included in Table II-6 only to further demonstrate their isolated nature and inconsistent pattern. Thus, only computation times can be considered in assessing motion effects. At least, the tested motions did not produce any obvious increase in errors or restarts, even with this "worst likely" keyboard configuration.

TABLE II-6

COMPARISON OF KEYBOARD TASK PERFORMANCE AT MEDIUM AND FULL SS 4, VS. CORRESPONDING STATIC DATA

a. Medium SS 4

SUBJECT	AVERAGE COMPUTATION TIME $\bar{T}_K$ (sec)			MEDIAN COMPUTATION TIME $T_{K_{med}}$ (sec)			ERRORS/TRIAL $\bar{N}_E$			RESTARTS/TRIAL $\bar{N}_R$		
	STATIC		MOTION	STATIC		MOTION	STATIC		MOTION	STATIC		MOTION
	PRE	POST		PRE	POST		PRE	POST		PRE	POST	
60	122.7	81.0	89.7	110	83	82	0	0	0	.33	0	0
61	100.	100.3	99.7	96	103	103	0	1.33	0	.33	0	0
56	84.3	78.0	129.0	85	75	137	0	0	0	0	0	.67
40	125.7	107	142.7	134	107	138	0	0	.33	0	0	0
43	–	81.3	89.3	–	86	85	–	0	0	–	.33	0
59	–	84.7	207.0	–	79	154	–	0	0	–	0	2.00
57	134.	70.0	108.7	105	70	112	.67	1.33	0	.67	0	0
51*	–	78.7	156.3		77	115		.33	.67	–	0	1.00
m ± σ	93.5±19.1		127.8 ±40.01	93.1±18.1		115.8 ±25.8						

b. Full SS 4

SUBJECT	STATIC PRE	STATIC POST	MOTION	STATIC PRE	STATIC POST	MOTION	STATIC PRE	STATIC POST	MOTION	STATIC PRE	STATIC POST	MOTION
60	81.0	68.0	78.7	83	65	78	0	0	0	0	0	0
40	96.3	84.0	144.7	97	84	151	.67	0	0	0	0	.67
40	84.0	–	225.0	84	–	188	0	–	1.33	0	–	2.33
52	95.3	–	195.7	92	–	162	0	–	0	0	–	.67
43*	85.3	60	73.0	83	62	74	0	1.33	0	.33	0	0
49	93.3	–	131.0	93	–	111	0	–	1.33	0	–	.33
51*	83.7	94.0	86.0	66	79	71	0	.67	0	.67	.33	0
m ± σ	84.1±11.4		133.4 ±59.6	80.7±11.8		119.3 ±47.8						

*These two subjects were members of the August team. They returned in mid-September to take part in further testing, during which their data shown in this table was obtained. Since their first formal run in September was at medium SS 4, there is no formal pre-motion static data for these at this condition.

Before motion effects on T_K can be assessed, learning effects must be accounted for in the determination of suitable static reference. Examination of available static pre- and post-motion average computation times for both medium and full SS 4 indicates the continued influence of learning on performance: data for four out of five medium SS 4 subjects and three out of four full SS 4 subjects show reductions (improvements) of 7.5 percent to 48 percent and 13 to 30 percent, respectively, in average computation time from pre- to post-motion static tests. Unfortunately, the small number of subjects in each of these comparisons does not allow for reliable testing of the statistical significance of this learning trend.

Taking the average among the subjects' median computation times as being most representative of "typical performance," the effect of medium SS 4 was to increase T_K by 24 percent (from 93.1 to 115.8 sec), and the effect of full SS 4 was to increase T_K by 46 percent (from 80.7 to 119.3 sec) over their relevant static times.

Another interesting observation is that in the nine cases permitting such a comparison in Table II-6 the average computation time under motion falls <u>between</u> pre- and post-motion static levels. However, this drops to only three of nine cases between if the more appropriate median times are used.

To further analyze motion effect, we first concentrate our attention on the full SS 4 data, because, as comparison of static data for both conditions shows, learning effect is less prominent therein than for medium SS 4 data, the former data having been obtained a greater number of days from the day of constituent subjects' first run, on the average. This data can be divided into two groups: (1) that for subjects 43, 51, and 60 (all of whom fortunately have pre- and post-motion static data available) whose average computation time under motion falls between (and within 20 percent of) its pre- and post-motion static values; and (2) that for subjects 40, 49, and 52 who show an increment (performance decrement) of 40 percent or more over static average computation time under motion. Consideration of the psychophysiological effects of motion on these six subjects explains this dichotomy. The former group, who showed little T_K decrement, all gave repeated kinetosis ratings of 1 ("no symptoms") during the runs on which these data were taken, while the latter group, whose T_K was much worse, all experienced emesis and quit the run on which this data was obtained not long after the Keyboard task was performed. [Subject 40, whose data is shown for two runs, felt "severe nausea" on the first of the two (a 6 hr run) before abandoning the second (long) run after 13 hr.]

This analysis of the situation indicates that for asymptotically well-trained keyboard operators who are kinetosis resistant, the direct motion interference effects would not result in a substantial increase in keyboard computation times (whether statistically significant or not), but that the indirect psychophysiological effects of motion with lesser trained operators could result in substantially increased computation times.

5. Specific Findings and Conclusions

The Keyboard task involved a chain of visual-motor subtasks potentially sensitive to SES motion effects, such as transcription of verbally transmitted data, operation of a small wall-mounted mincomputer with arm outstretched, copying results from the small digital display on the minicomputer, and verbal transmission of the results. Not too surprisingly, this complex array of manipulations resulted in continued learning throughout most of the static and motion runs, thereby making difficult the analysis of the relatively small effects of SES motions.

The specific findings were as follows:

a. Under static conditions the median of all subjects' average time to complete the Keyboard task continued to improve from about 125 to 80 sec, with an 8 day learning time constant.

b. On the average, there were much fewer than 1.0 computing errors per problem and fewer than 1.0 restarts per problem, with no apparent pattern to the differences among crewmen under either static or motion conditions. The scarcity of such errors precluded statistical analysis, and the somewhat surprising absence of any apparent trends in such errors precludes any positive statement as to motion effects.

c. Occasional restarts tended to skew the distribution of computation times so that median computation times for a given subject are the most appropriate measure of Keyboard performance.

d. Relative to their corresponding pre- and post-motion static tests, in the only two conditions where sufficient data exist to make matched pair comparisons, motion increased the typical Keyboard computation times by 24 percent in medium SS 4 and by 46 percent in full SS 4. However, these increments barely exceeded the typical standard deviation among subjects, and so were not statistically significant.

e. In SS 4 conditions, one group of subjects who indicated "no symptoms" of kinetosis retained Keyboard task performance within 20 percent of static levels, while the others who had severe motion sickness dropped more than 40 percent in performance.

It is concluded that SES motions of the type simulated would decrease performance on well-trained Keyboard tasks only slightly, on the order of the scatter among various operators. Subjects who were not prone to kinetosis showed no motion interference while some subjects who were strongly susceptible showed more severe loss in performance, probably due to indirect psychophysiological effects of motion sickness. In view of the fact that an extremely small keyboard was used as a worst likely case, any more reasonable keyboard design having larger, heavily detented keys, would probably not suffer in performance under these typical SES motions.

6. Recommendations

It is apparent, in hindsight, that much more intensive training, both under static and motion conditions, should be given to the subjects in order to achieve a more asymptotic performance for such a complex visual-motor task. About one week of twice daily practice would be required. In view of the small effects of motion on even this worst likely keyboard configuration (where the fingers could be braced even when the arm was not), it may not be cost effective to continue this task as a sensitive measure of SES motion effects. It can serve as a highly motivating and "face-valid" task to fill in the crew's activities with operational-like tasks should that be necessary.

E. LOCK TASK

1. Rationale and Approach

The Lock Task is intended to measure motion interference with fine-motor manipulations, such as might be typical of opening code safes, adjusting machinery, or tuning a radio. It involves dialing in the four-number combination of a low-friction, precision combination lock using only one hand, with an outstretched arm. The primary measure of performance is the time required to correctly open the lock, T_O, while the number of restarts, N_R, serves as a supplementary performance measure which may give insight into whether any observed decrement in opening time is the direct result of motion-induced errors or the indirect consequence of modifications (slow down) in technique.

Subjective motion interference with the Lock Task is also rated on the Habitability Evaluation Questionnaire as a measure of increased visual/motor workload (see Subsection III-D).

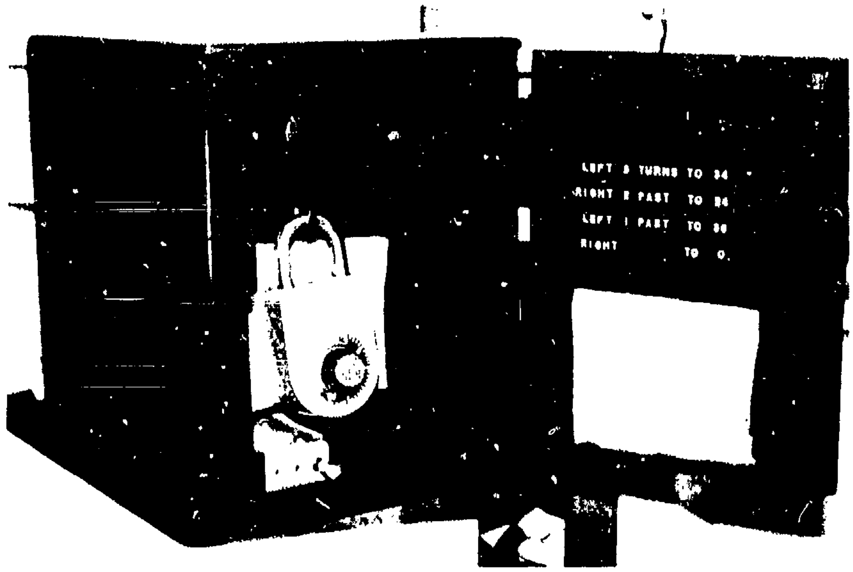
For face validity, the Lock Task was incorporated into the cryptographic task scenario (HFR was responsible for the latter task which is described in Volume 4, Ref. 19). The Encoding Task and Decoding Task materials were kept in a small safe-like "lock box" on which the lock was installed. As a prelude to either of the above coding tasks (encoding or decoding), the subject had to open an outer door, the four-combination lock, and an inner-door in order to access the code materials.

This same task was employed in the MSFC and the SESP/ONR/HFR Phase I, IA simulations, where it was readily accepted by the crews (Refs. 2 and 6).

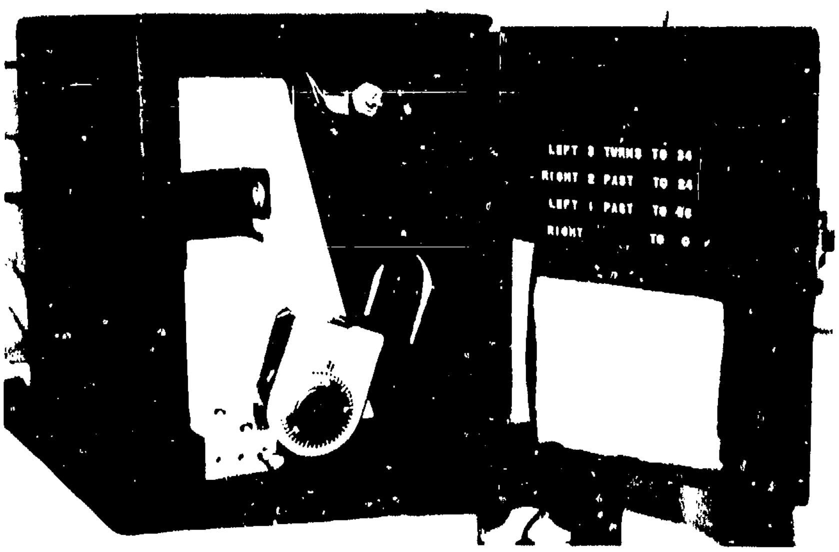
2. Apparatus

The lock box was located on top of the microwave oven, next to the work bench, as shown in Fig. II-22a. It consists of a plywood box with inner and outer hinged doors like a small safe. The lock, a Sargent and Greenleaf low-friction, precision four-combination high-security lock, was installed on the inner door as shown in Fig. II-22b. Its combination is posted on the back

a) Subject Performing Lock Task



b) Lock Box With Outer Door Open, Lock Engaged



c) Lock Box With Lock Disengaged, Inner Door Open

Figure II-22. Lock Task Setup

side of the outer door. Progressively fewer whole turns to the left or right past the last number are required, demanding close attention to the dial and proper memory of the turn's count and last number.

Spring loaded switches are mounted to the box frame where the inner and the outer doors close so that opening either door trips a switch. These switches are cable connected to the "Lock Task meter," on the STI Experimenter's panel, on which the door status is indicated. The task is timed with a stopwatch from indication of "outer-door-open" to "inner-door-open."

3. Procedure

The seated crewman initiates the Lock Task by opening the outer door of the lock box. With one outstretched (unsupported) hand, the subject dials in the lock combination, opens the lock, removes it from the hasp, and opens the inner door of the lock box. If the subject knowingly errs in entering the combination, or if the lock cannot be opened after the combination is complete, the subject so informs the Test Conductor and re-dials the combination, repeating this procedure until the lock is opened. Generally, the subjects were careful at each stage so errors were not apparent until the lock failed to open.

The Test Conductor timed the task, starting the stopwatch when the Lock Task meter indicates that the outer door has been opened, and stopping it when the meter shows that the inner door has been opened. He logs this lock opening time and the number of restarts on an Operator's Data Sheet (Appendix A), along with the subject's code, date, and time.

About 5 minutes per test are involved in total. Single Lock Tasks were done twice per 24 hr during the long runs at about 0400 and 0500 by the day sleeper and about 1600 and 1700 by the night sleeper. During the 6 hr runs only one trial was done either 2 or 4 hr (nominally) into each run.

4. Results and Discussion

Because the Lock Task was done twice, each time (during decoding and encoding), the values were averaged to obtain a representative score for the test period. These basic scores are plotted for each subject in Fig. II-23 in the format used previously, i.e., grouped by test condition.

The process of learning to open these locks had two distinct stages: (1) the subject had to get the knack of the "n turns past x" instructions and to remember the combination (posted on the door), a knack which some got instantly while others took several trials, (2) improvement in precision of twisting and reduction of error, resulting in a steady improvement in opening times.

Despite a few days of practice over more than a dozen trials, the static data in Fig. II-23 clearly indicate continued learning throughout the test program. As in earlier plots, the median lock opening times are fit by the likely static trend given by:

$$T_O \text{ (sec)} = 23 + 11e^{-\Delta \text{Day}/3} \text{ (sec)} \qquad (18)$$

Thus the performance improves by a factor of two (from 33 sec initially to a 23 sec asymptote) with a roughly 3 day learning time-constant. However, there is wide scatter about this trend line and evidence of strong skew towards higher times despite the log transformation plotted in Fig. II-23. The reasons for this will be discussed later.

Consideration of each of the motion condition effects of Fig. II-23 reveals that almost every motion condition [except the lowest (2/3) SS 3] resulted in a group median below (worse than) the static trend line superimposed on each for comparison. However, there is no clear pattern to the loss in performance among the conditions in terms of either the opening time, T_O, or the reported restart errors per trial, N_R.

In view of the small number of samples per condition and the roughly similar decrements for each, we have simply plotted matched pairs of premotion static versus motion data for each subject, as shown in Fig. II-24.

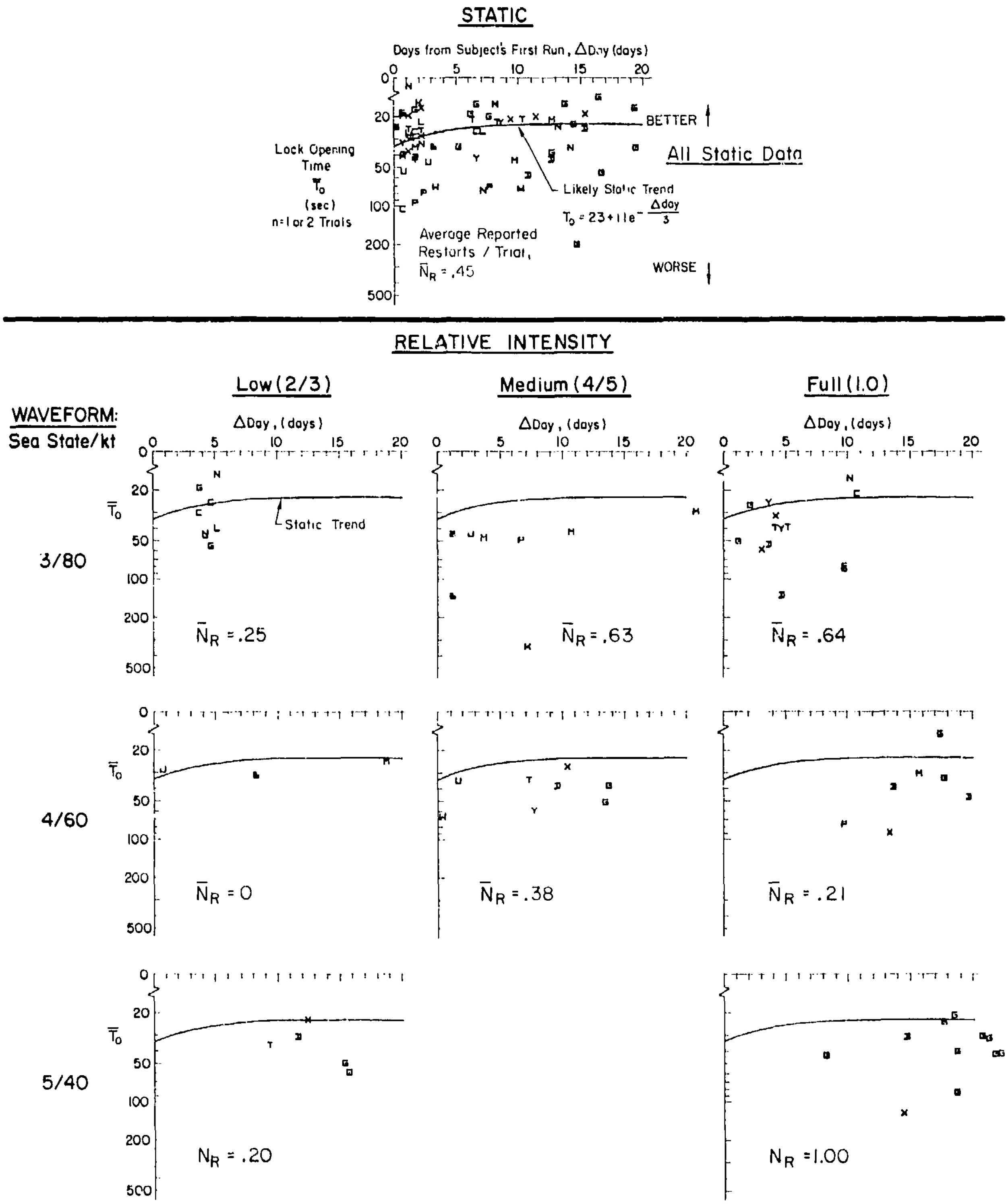


Figure II-23. Basic Lock Task Data for Each Subject Versus Time, Grouped by Test Condition

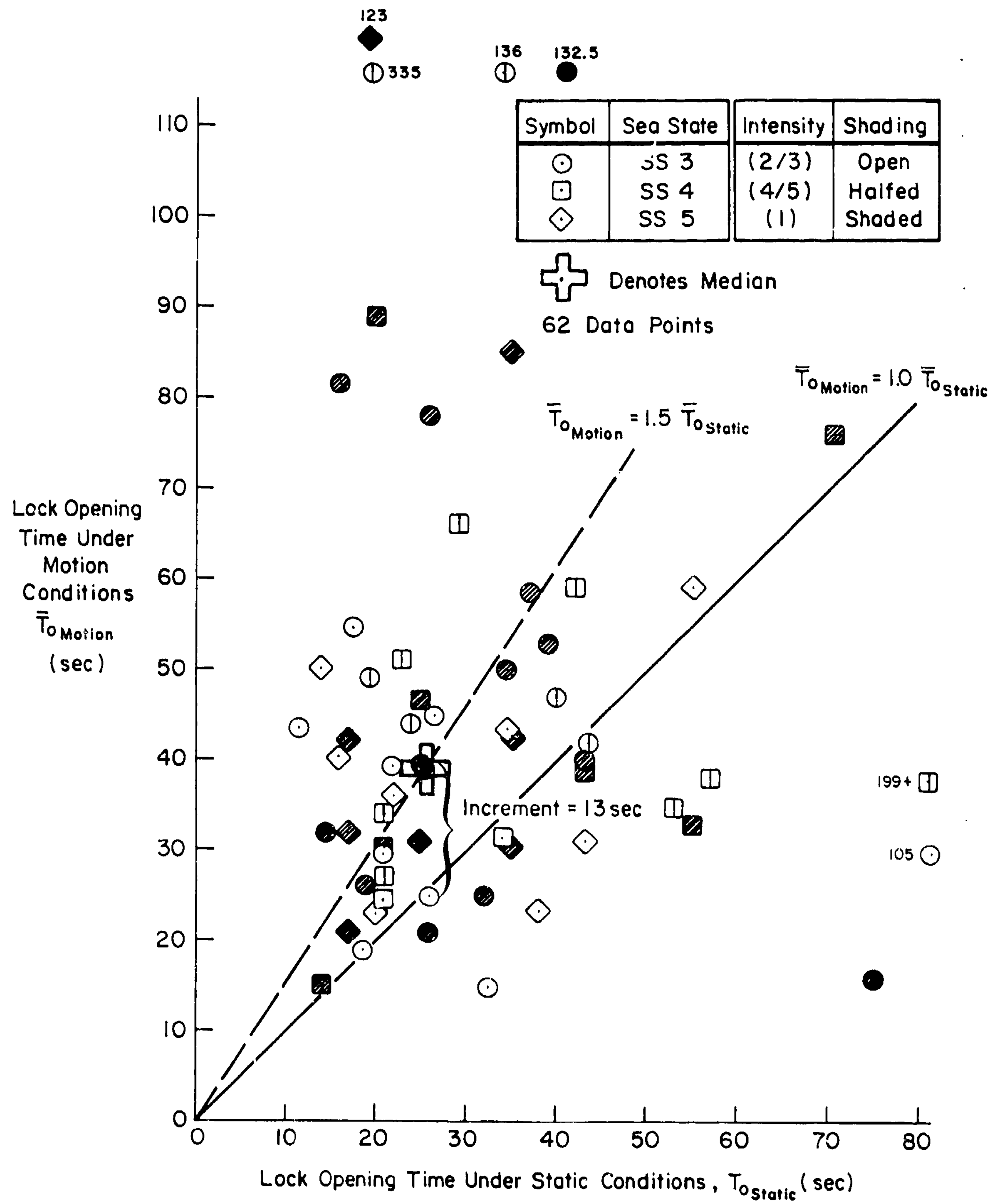


Figure II-34. Comparison of Matched Static Versus Motion Lock Opening Times For Each Subject

There does not appear to be any correlation of T_O with motion condition; data for the higher frequency waveforms of SS 3 (⊙ symbols), which might be expected to affect fine-motor precision, seem to be intermingled with those of lower-frequency waveforms (SS 5 = ◇).

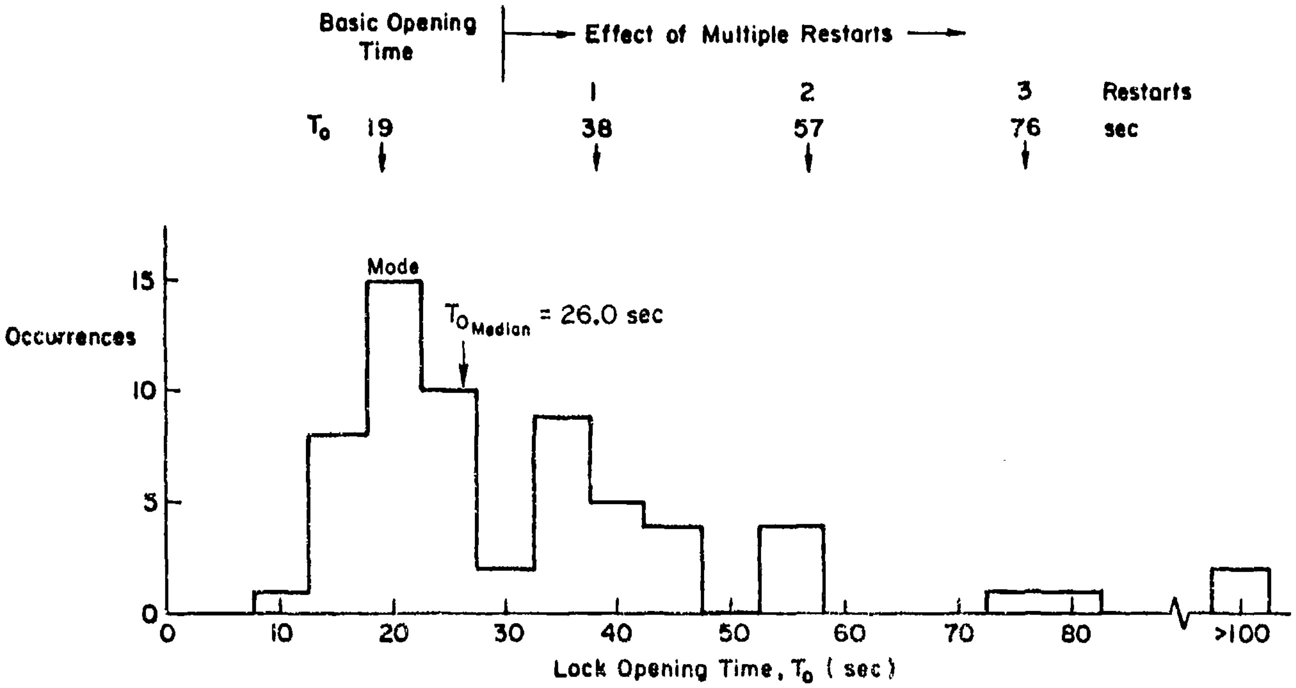
The median opening time among all (pooled) motion conditions (39.5 sec) is about 1.5 times as long as the pooled static median (26 sec), or is an increment of 14 sec out of 26 sec. It is probably more valid to consider the ratio of motion-to-static opening time, because, as subsequent paragraphs will show, several of the opening time components increase in rough proportion to each other, thereby increasing the overall time proportionately. The highly skewed and multimodal distribution of lock opening times (illustrated later) precluded parametric statistical analysis. Even nonparametric analyses would be invalid for the multimodal distribution we see here. However, for the matched pairs shown in Fig. II-24 a simple one-tailed Signs Test for the direction of change between static and motion conditions was made, and it proved significant at $p < 0.001$. That is, very reliably, a typical crewman's lock opening time would increase for any motion above low SS 3 (0.13 G_z). The ratio of motion-to-static opening times averages 1.5, but the 90 percentile range is from about 0.6 to 3.0.

Further insight into the components of the Lock Task performance is gained from histograms of the T_O distributions, both static and under motion, which are given in Fig. II-25. Two salient features are immediately apparent on Fig. II-25:

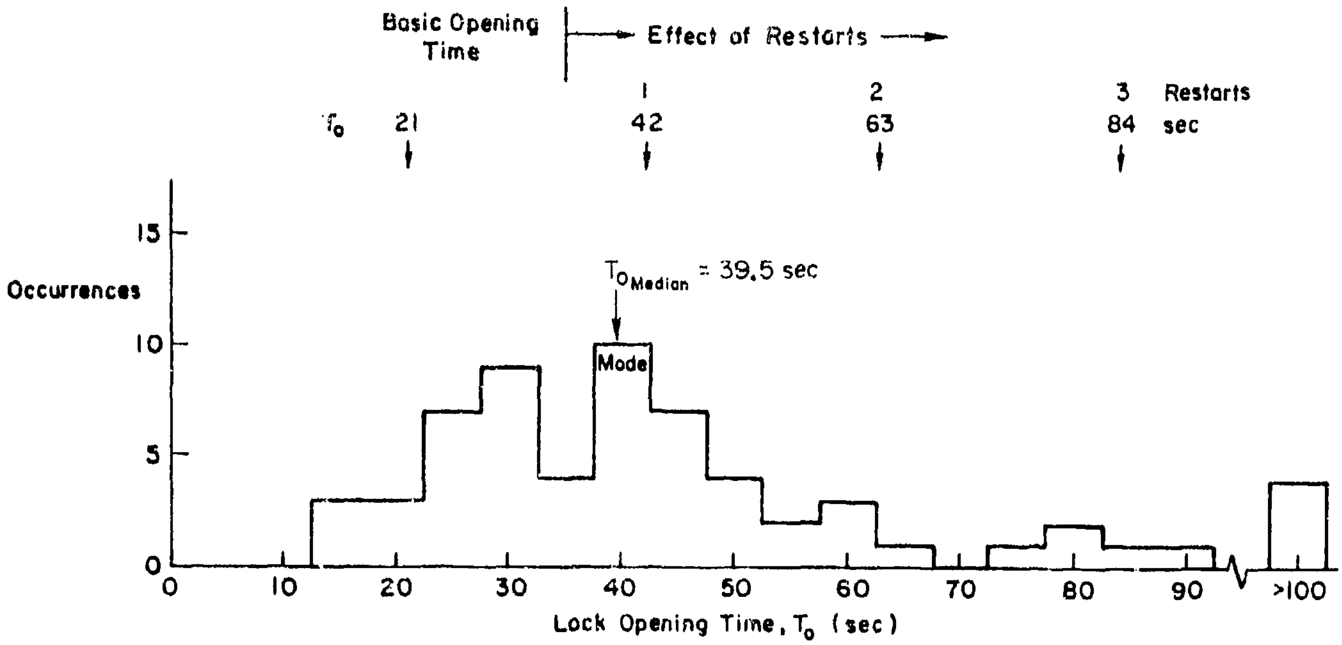
- The distributions are highly skewed, with long tails in the high time direction.
- They are multimodal, having three or four distinct peaks.

Further consideration of these histograms, along with anecdotal comments made during the debriefings by certain crewmen, leads to the following hypothesis about these data:

> There is for each subject a "basic" lock opening time on the order of 20 seconds, if all goes well on the first try. If any hidden errors are made, they will not be apparent until all four numbers have been cycled through (in roughly 20 sec). Each time there is a restart the opening time increments by this basic amount, leading to a histogram with peaks at the basic time and multiples thereof.



a) All Static Conditions



b) All Motion Conditions Combined

Figure II-25. Histograms of Lock Opening Times, Static and In Motion

This hypothesis was suggested by the static T_O histogram at the top of Fig. II-24, where distinct peaks at around 19, 38, 57, and 76 sec are visible, corresponding to 0, 1, 2, and 3 restarts. The basic time peak is smeared due to inter-subject variability and learning.

In support of this explanation of the T_O distribution "tail" is the fact that 47 percent of the occurrences lie beyond the 0 restart band in Fig. II-25, while 45 percent restart rate was logged (N_R = .45).

Under motion, the basic lock opening time apparently rises a few seconds from 19 to about 21 seconds, with multiple restart peaks visibile near 42, 63, and 84 sec. Also under motion the one restart peak is the mode whereas the zero restart peak was modal under static conditions. The data suggest a restart ratio of 62 percent, considerably higher than most reported N_R but not unreasonably so.

The motion histogram peaks are more smeared than their static counterparts because of higher individual differences, more variability in basic opening time and from start to start, and probably some detected errors partially through the combination.

The foregoing analysis reveals that the 50 percent increase in median lock opening times is due to two basic causes: (1) an increase in the basic opening time of about 10 percent (from 19 to 21 sec), which spreads out all the multiple restarts to form a longer tail; and (2) about 38 percent more restarts (from 45 to 62 percent), which shifts the centroid of the distribution to higher times. Thus, both speed and accuracy suffered moderately under motion, and the median lock opening time provides a sensitive and useful combined measure of these effects.

The specific effects of all motions, pooled, relative to time-matched static performance were as follows:

- The basic opening time increased 10 percent (from 19 to 21 sec).
- The number of restarts per opening increased 38 percent (from 45 to 62 percent).
- The resulting median lock opening times increased by 52 percent (from 26 to 39.5 sec).

Because of the pooling of different conditions, and the highly multimodal and skewed distribution of opening times, no statistical tests were performed on these quantitative increases. However, it is clear upon inspection of the basic data plots, for this group of subjects, that there is an appreciable motion interference effect on lock opening which was not systematically related to the intensity of motion.

The above results are roughly consistent with those found in MSFC simulations (Ref. 2) and Phase I, IA results (Ref. 6). In Phase IA, for example, the median static opening time was about 22 sec, which increased to about 33 sec under SS 3 or (2/3) 4 motions, and evidence of multiple restarts and insensitivity among three motion conditions was noted (Ref. 6).

5. Specific Findings and Conclusions

Fine-motor operations were tested by the Lock Opening Task which measured the time and number of restarts to open a very low-friction, four-combination security lock.

Analysis of the highly skewed and multipeaked histograms revealed peaks at a basic opening time (about 20 sec) and multiples thereof indicating successive restarts. Under static conditions, the basic opening time was around 19 sec with 45 percent restarts, for a median lock opening time of 26 sec among all subjects.

Only the least severe motion condition (low SS 3 with .13 rms G_z acceleration) showed little change from static. Under all other motions there was a ten percent increase in opening time and 38 percent more restarts for most subjects and conditions, but no systematic pattern which could be correlated with motion properties. The tendency for worse performance under motion was highly significant statistically ($p < 0.001$; one tailed Signs Test).

6. Recommendations

The Lock Test has proven to be an useful one for motion habitability investigations. The apparatus is simple and the required low-friction locks are widely available; the task is easy to set up, train for, and score; the task is readily accepted by crewmen as having face-validity with respect to a class of operational tasks, and the median opening time measure is sensitive to interference with fine-motor control.

The skewed, multipeaked distribution of opening times among a group of subjects makes mandatory the use of nonparametric statistical measures such as median times. However, the mutliple restart hypothesis advanced and tentatively validated herein offers a way for further diagnostic analysis of time and restart data from which the underlying causes of performance change might be deduced.

We recommend retention of the Lock Test, using identical types of locks and procedures (especially the measurement of time to open and number of restarts reported) in future SES habitability programs. A large number of tests should be made to provide an adequate basis for the required nonparametric statistics. The apparent insensitivity of the Lock Task scores among various conditions is not serious, because there is evidence (albeit meager) that a sort of threshold trend is operative, i.e., below a certain level of motion interference (here, about 0.15 g) there is little effect, while above it there is a sharp increase in opening time (here 50 percent) due to both slower and less accurate performance. Future use of lock opening statistics should be considered from this point of view.

F. MAINTAINENCE TASK

1. Rationale and Approach

The Maintenance Task is designed to determine the effects of motion interference on the ability to perform electro-mechanical tasks typical of maintaining small shipboard electrical equipment. The task consists of the removal of both mechanical (e.g., screws, nuts) and electrical (e.g., resistors, capacitors) parts from a standard (surplus Navy equipment) power-supply circuit board. The only tools used are a soldering gun, needle-nose pliers, and a standard screwdriver. The task was selected to be simple enough that past electronic experience would not be necessary for good performance, yet complex enough to exercise a variety of tool manipulations under motion.

Task performance parameters include: parts removed in intact condition, parts removed in damaged condition, and the time taken to remove all parts. The degree of motion interference is measured by the reduction in the circuit board disassembly rate. This score is defined as:

$$\text{Weighted Disassembly Rate} = \dot{D} = \frac{\text{(parts removed, intact)} + 0.5\ \text{(parts removed, damaged)}}{\text{Elapsed time}}$$

where elapsed time equals time to remove all parts, or 30 minutes, whichever is greater. It provides a weighted and time-normalized measure of performance with low sensitivity to individual circuit board variations and to precise time limitations. A high disassembly rate represents better performance, and subjects were encouraged to work rapidly but carefully.

Subjective impressions of motion interference on this task were also rated on the Habitability Evaluation Questionnaire (see Subsection III-D). In fact, one of the prime reasons for performing this task was to form a realistic basis for evaluating the motion interference subjectively.

2. Apparatus

The equipment used for this task is shown in Fig. II-26. It consists of:

- A number of identical power supply circuit boards for shipboard radar equipment (obtained at a surplus store), each of which had four nearly identical power-supply sections of which one at a time was disassembled (the rest being wrapped with tape).
- A lightweight pistol grip soldering iron (Weller No. GT) stored in a spring holder bolted to the work bench.
- A common screwdriver with 3/16 in. blade.
- A pair of needle-nose pliers.
- A pair of safety glasses to be worn while performing the task.

The task was performed at the work bench (Fig. II-1). The soldering gun was intentionally marginally hot for the heavy copper wires and bus-bars involved so that considerable dexterity and maneuvering were required to simultaneously melt the solder and unwrap the wires from their attachment post without breaking the part.

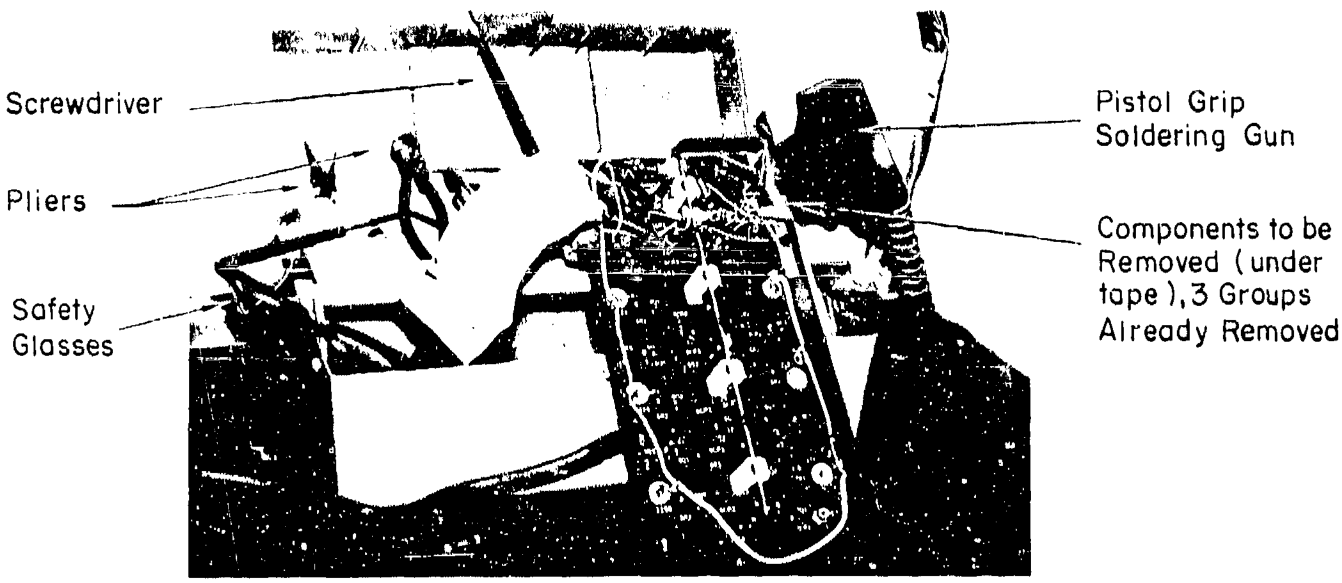


Figure II-26. Maintenance Task Apparatus

3. Procedure

This task is performed with the crewman seated at the work bench where he has access to only the soldering gun, the screwdriver, and the pair of needle-nose pliers. When the Test Conductor says "GO," the crewman removes the tape from one (of four) segments of the power supply circuit board. (He has been instructed to remove all parts individually from the board segment as rapidly as possible without damaging them.) The crewman places the parts he has removed in a manila envelope. The Test Conductor starts the stopwatch when the tape is removed from the circuit board, and stops it when the crewman has removed all parts from the circuit board and sealed the envelope or when 30 minutes are up. If the crewman uses the whole 30 minutes, he is instructed to stop work and seal his envelope immediately; and the watch is stopped as he seals the envelope. The crewman is then instructed to write his name and the data and time at which the test was finished at the top of the envelope and to put it in the "mailbox."

The Test Conductor records the elapsed time, along with the crewman's code, date, and start and finish times on the Operator's Data Sheet (Appendix A). The sealed manila envelopes are later opened, the removed parts classed as intact or damaged by an experienced lab technician (all were judged by the same individual, D. S., and tallied, and the weighted disassembly rate computed for each test.

The Maintenance Task was scheduled to be done once per 24 hr on the long runs, at 2100 by the day sleeper and at 0900 by the night sleeper; and once during the 6 hr runs, either 2 or 4 hr into each run. However, it was actually performed considerably less often than scheduled, due both to the limited number of surplus circuit boards available and to the length of time required for the task, which made it difficult to fit in when other things did not go according to schedule.

4. Results and Discussion

The basic results are plotted in similar format as the previous tasks on Fig. II-27. A log transform of the weighted disassembly rate, $\dot{D}$, in parts/minute was used to even out the distribution and to facilitate comparison of

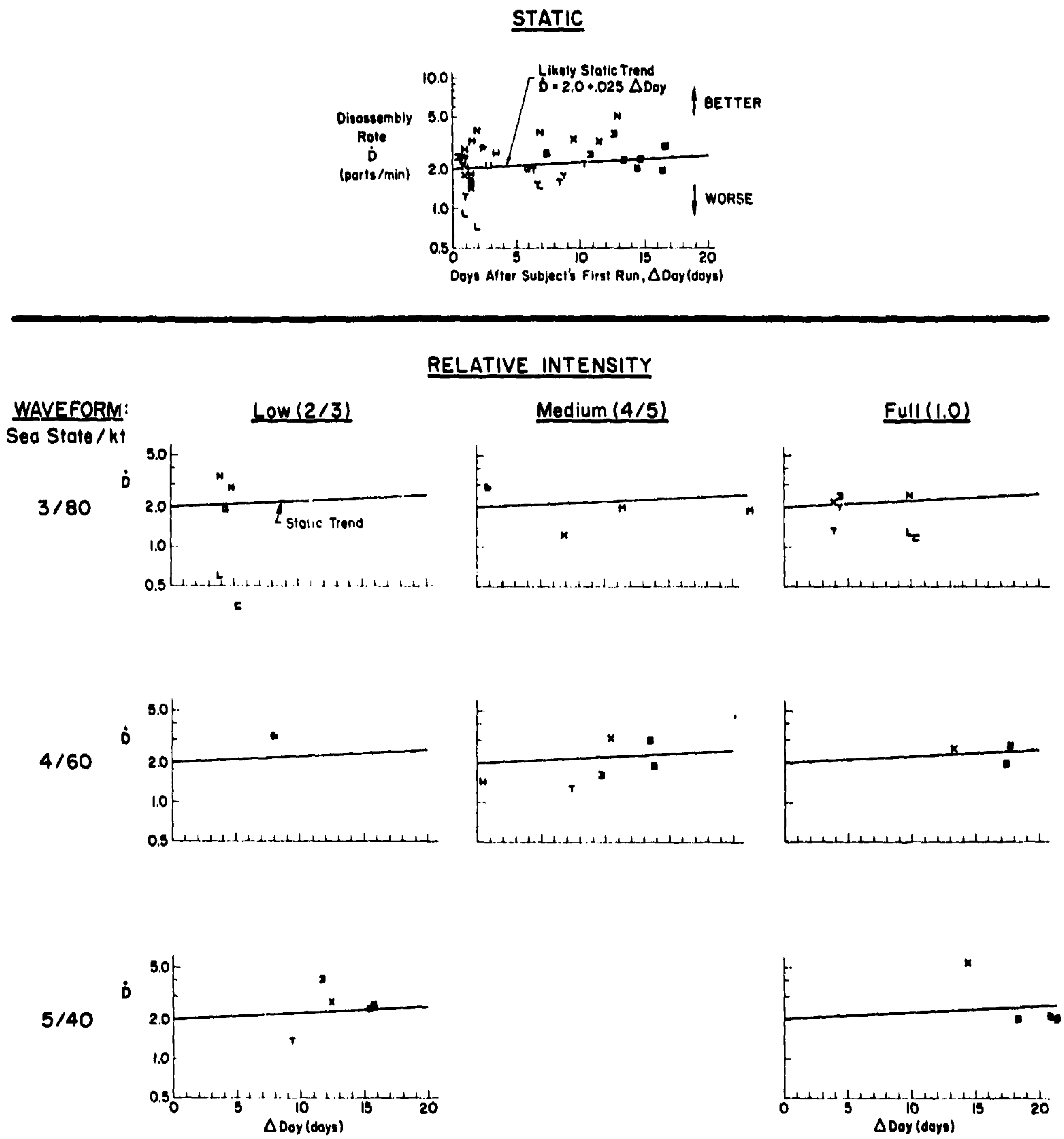


Figure II-27. Basic Maintenance Task Data for Each Subject Versus Time Grouped by Test Conditions potential effects of motion causing percentage decrements which become even dimensions on a log scale. (The latter reason was unnecessary, in hindsight.)

Considering first the static data, at the top of Fig. II-27, we find a wide range of performance among subjects and a continuous improvement throughout the test period, with no suggestion of an asymptote as in the other tasks. Therefore, the likely static trend through the medians is approximated by a straight line:

$$\dot{D}_{med} = 2.0 + 0.025\ \Delta\text{Day} \tag{19}$$

This implies that the typical subject could disassemble 2.0 parts per minute at the start, and about 2.5 parts per minute by the end of the three weeks of testing, representing a gradual improvement in $\dot{D}$ of just over one percent per day. This gradual improvement is not too surprising in view of the lack of training and the complex maneuvers required, which take a long time at which to become adept. The range of $\dot{D}$ was a factor of two on either side of the trend, representing primarily different skill levels and "style of work" among different subjects. Regarding the matter of style, debriefing comments revealed that some subjects (notably those having some electronic experience) were quite careful not to distort or to break parts, while others (especially two subjects naive to electronics) simply tore parts off as fast as they could melt the solder, with little regard to damage. Thus, the more electronically experienced subjects were often the slowest performers. Since a variety of such styles is typical of operational personnel, we have not attempted to sort out the "carefuls" from the "hackers."

For reasons mentioned earlier, there were far fewer maintenance tasks tests per motion condition than other tests so the motion data in Fig. II-27 form a rather sparse matrix from which to judge anything. Nevertheless, <u>it is apparent that there is no obvious decrement at any motion condition</u>, with the points well distributed around the median static trend in all cases.

Review of the debriefing comments revealed that the reason for insensitivity of $\dot{D}$ to severe motion was due to the highly intermittent nature of the parts removal operations and the low frequency of such operation (about 2 per minute). Any increases in the actual removal process were completely lost in the long between-removal intervals. The work was subjectively more difficult under large motions (reported later), but the performance was not much affected.

A correlation plot for matched pairs of static versus motion conditions is given in Fig. II-28. Each point is for a given subject with the static case chosen as the closest to the motion data. It is apparent that the changes in $\dot{D}$ from static to motion condition were roughly proportional to the subject's static level, as evidenced by the even dispersion of points between the 0.6 and 1.4 $\dot{D}_s$ lines. Not revealed in this plot is the observation that given subjects tended to have clustered groups of points, either above or below the line and at generally high or low levels of $\dot{D}$.

More germane to this investigation is the fact that there is no apparent trend among the various motion conditions, with the various coded symbols scattered uniformly over the plot. The median disassembly rates decreased from 2.55 parts/minute among all static cases to 2.02 parts/minute among all motion conditions; a 20 percent decrement in typical performance due to motion.

Considering that about 8 of 32 cases in Fig. II-27 (actually reflecting 5 individuals' data) performance under motion actually improved and that the range of $\dot{D}$ under motion ranged from about 60 percent to 140 percent of static, the 20 percent drop in median performance is not statistically significant.

5. Specific Findings and Conclusions

A task simulating electrical equipment maintenance and repair operations was performed by many subjects in most motion conditions. Because the operations involved complex maneuvers such as: manipulation of a densely packed circuit board, simultaneously unsoldering and unwrapping with pliers a variety of thick wires wrapped to posts, and handling of fragile electronic parts without breakage; there was a wide range of individual performance and gradual improvement throughout the test period. Evidence was obtained that distinct, individual "styles" of work (wherein electronically experienced subjects often performed more slowly) accounted for much of the range of data.

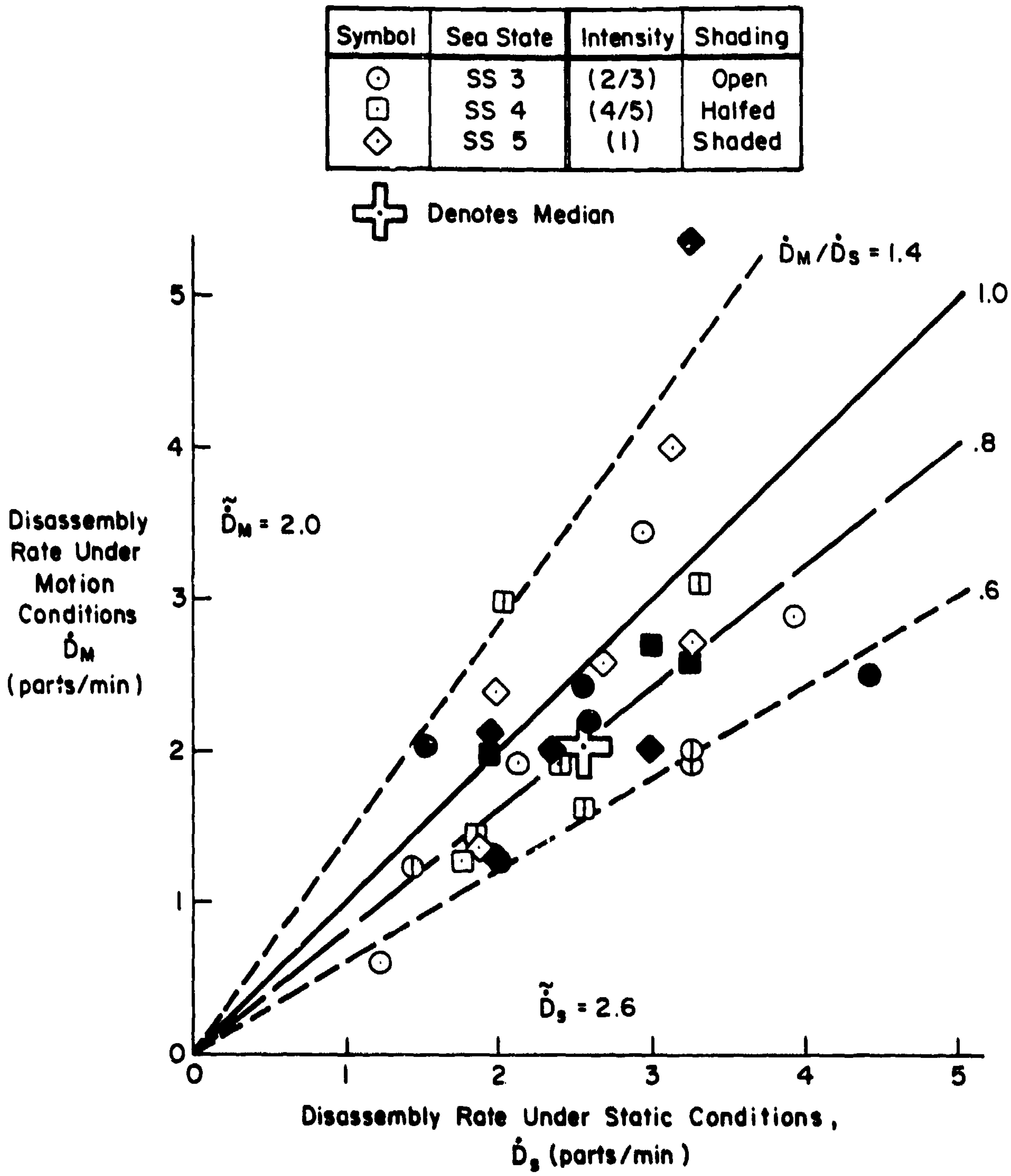


Figure II-28. Correlation of Maintenance Task Performance Under Motion Versus Static for Each Subject

The measure of performance was a weighted disassembly rate $\dot{D}$ in parts/minute. About 75 percent of the cases (subject-conditions) showed a decrement in $\dot{D}$ under motion and 25 percent an increase in $\dot{D}$, with the median among cases going from 2.6 parts/minute static to 2.0 parts/minute under all motions; a roughly 20 percent impairment.

There was no systematic effect on $\dot{D}$ among various motion conditions, with even low SS 3 showing some decrement, in contrast to most of the pattern of previous tasks.

Although the crewmen found the task subjectively more trying under motion, the performance did not suffer seriously. This was traced to the intermittent and occasional (twice per minute) nature of the actual part removal process so that appreciable increases in actual removal time did not impact strongly on the overall rate of performance.

It is concluded that SES-like motions of the type simulated would have relatively minor adverse effects on the performing of most electromechanical maintenance tasks on small equipment, even though the subjective workload would be greater.

6. Recommendations

Although every effort was made to control the task difficulty (by using identical circuit boards, preliminary training, and requiring only disassembly operations), the complex operations involved and individual styles resulted in a wide range of data and variability. Consequently, such a task is best given as a "hands on" basis for subjective evaluation of motion interference, rather than as a scorable tests.

G. LOAD TASK

1. Rationale and Approach

The ability to handle and transport equipment and material is of considerable importance in shipboard operations, and the effects of motion on this ability are of interest in such a study as this. The load task was designed to give each crewman experience with handling a typical electronics rack under motion conditions at various postures, in order to more accurately evaluate this type of activity.

The surrogate load was a 14 pound wooden box similar in outline to a rack of electronic equipment. The load was passed up to the crewman, via the large canvas "mailbag," maneuvered through the sidewall hatch, thence through a series of prescribed positions simulating various load handling postures, and returned thereafter via the same mailbag on its return journey. This pass-up-and-back approach avoided the problem of storing such a bulky, heavy load in the moving cab, and it added to the required load handling maneuvers.

The subjective difficulty of the task is assessed as part of the Habitability Evaluation Questionnaire. No objective score was assessed.

In both the MSFC SES Simulations (Ref. 2) and the Phase I Simulation (Ref. 6), the same load had been used in some sort of load handling task. The earlier simulations showed that no useful performance score could be measured since crewmen merely worked harder to compensate for motion interference with balancing or manipulations. It was added to Phase II after debriefing comments indicated that there was insufficient basis on which to evaluate load handling on the Habitability Evaluation Questionnaire.

2. Apparatus

The apparatus consisted of a rectangular 14" × 10" × 7" wooden box with two typical electronic rack handles mounted on the 14" × 7" side. Lead weights were fastened to the inside of the box to give it a gross weight of about 14 lb (30 Kg). This load was hauled into the cabin in a large canvas "mailbag" through a hatch in the cabin floor, as part of the task.

3. Procedure

The load task was done in the following manner:

a. The Test Conductor initiated the task by announcing to the crewmen: "Ready for mail and load handling." He then had the black box put in the mailbag lowered by the crewman.

b. The following sequence of instructions was to be carried out by the crew:

   i. First man hauls in the mailbag; second man stands on opposite side of navigation chair.

   ii. First man extricates black box from mailbag while squatting near hatch and hands it up to the other man, over the navigation seat. (This is to catch load if it slips.)

   iii. Second man places black box on floor under CRT, squatting en route, as if placing it on a shelf. Then, stand, lean over, pick it up, and hold it as if walking down a corridor.

   iv. (For September crews only.) Then, moving to the refrigerator area, he squats and slides it into the brackets provided under the work bench (as if into an electronics rack).

   v. When ready to return the mailbag, first man slides black box out of the brackets, maneuvers it into the mailbag, and lowers all to the waiting assistant below.

   vi. (Each man) notes the difficulties he had on his Habitability Evaluation form.

   (Crewmen were to alternate in the first- and second-man roles on successive mail deliveries.)

As noted earlier, the Load Task was reinstituted in Phase II for the August runs only. The task was initially so easy that there was little to evaluate, so the requirement to insert it in a sliding bracket was added in September. It was scheduled twice per 24 hr during the long runs at 0815 and 2015 and once at 4.5 hr into the 6 hr runs.

Unfortunately, the pressure of other events, combined with a low priority rating on this task, often led to omission or incomplete performance of the Load Task.

a) Squatting

b) Lifting

Figure II-29. Subject Performing Load Task

4. Results and Discussion

As reported in the debriefings, the crews had no problem manipulating this 14 pound load through the required maneuvers. Holding the load out in front of the subject for one-minute periods during SS 5 was "noticeably more tiring" to two of five subjects queried. Most subjects found the handling of this load a "trivial exercise" for conditions under 0.20 G_z rms.

No practice in climbing stairs or ladders with such a load could be given in the small cab, but subjects indicated "likely difficulty" with such operations unless good railings were provided.

The subjective ratings on the Load Task are given in Subsection IV-D, but are very meager due to the factors mentioned above.

5. Specific Findings and Conclusions

The Load Task involved maneuvering a 14 pound (30 Kg) black box (simulating a typical electronics rack) out of a canvas mailbag, handing it to a partner, moving about carrying it, standing and squatting, and (for September only) sliding it into a simulated rack mount. Only subjective evaluations of the difficulty of performing these maneuvers were scored.

The subjects indicated no problems at any sea state under 0.20 G_z rms and only a few problems at full SS 5.

It is concluded that handling modest loads typical of electronics racks or storage boxes, having handles such that one hand can be used to carry the load and one hand for bracing the subject, will not cause appreciable problems in level maneuvers at conditions up to SS 5. At the higher sea states, stair, step, or ladder climbing will provide some difficulty while carrying such loads.

6. Recommendations

Even though this modest-weight handled load proved no difficulty at most of the conditions and was, therefore, considered a trivial task by most subjects, we recommend that some form of load handling be included in future habitability simulations to give subjects first hand experience on which to judge the motion interference.

The presence of two sturdy handles was reported as a key factor in making the load handling a simple task, and this has two implications:

- All loads to be handled in SES under similar motion conditions should have sturdy handles suitable for one hand carrying.
- A more challenging Load Task would involve handling a bulky, modestly heavy load (i.e., a large cardboard box with padded weights inside) without handles.

We are concerned lest the apparent ease of handling the black box in these runs leads to complacency about what could be a more serious problem: the handling of bulky loads, especially on stairs and ladders under severe sea states.

SECTION III

SUBJECTIVE EVALUATIONS

A. GENERAL RATIONALE AND APPROACH

Many of the questions regarding SES habitability in rough sea conditions can best be answered in subjective terms. When psychological rather than physiological effects are the prime behavioral effects of motion, subjective evaluations, properly formalized, are appropriate measures of habitability. Some of the previously described task results showed that small decrements in performance may be the result of extra effort by a crewman to compensate for motion interference, and this effort can best be measured introspectively. Ratings are sometimes the only feasible way to assess motion interference with complex functions such as life support activities, maintenance tasks, etc.

Years of successful experience in the collection and application of aircraft "flying qualities" evaluations have shown that such measures can be made reliable (in test-retest and population validity senses) and highly informative to designers by judicious choice and consistent use of rating scales and interrogation technique (e.g., Ref. 21). Consequently, a set of habitability evaluation scales has gradually evolved over the course of this experiment series which began with the SES simulations at NASA's Marshall Space Flight Center in 1973 (Ref. 2) and refined in the Phases I and IA programs in 1974 (Ref. 6).

As identified in Table II-1, three categories of subjective evaluation were assessed: A. "Kinetosis" or motion sickness; B. "Overall Environmental Rating"; and C. "Specific Task Interference." The scales used for each were arranged on a compact Habitability Evaluation Questionnaire (HEQ), shown in Fig. III-1. This form was used by the July and August teams. A slightly refined and less crowded two-page version of the questionnaire was created for the September team and is included in the appendix. (In this final version, the specific task interference scale, which was rated much less frequently than the other two categories, was put on a separate page in slightly modified format, and the wording on a few of the questions was changed for clarity, on the basis of crewmen's debriefing comments.)

HABITABILITY EVALUATION QUESTIONNAIRE

Note: Numbers in parentheses are used for scoring; Not on subject's form

PHASE II RUN NO.______

CREWMAN______________________________ DATE: ___/___/___ (YEAR MONTH DAY) TIME __:__ HRS. INTO MISSION ______

(Put any additional comments on reverse side.)

A. KINETOSIS (MARK THE SCALE)

LEVEL:	RATING	
NO SYMPTOMS	0	(1)
STOMACH AWARENESS	1	(2)
MILD NAUSEA	2	(3)
MODERATE NAUSEA	3	(4)
SEVERE NAUSEA	4	(5)
EMESIS OR RETCHING	5	(6)

COMMENTS: ____________

CHECK YOUR TENDENCY TO:

	NONE (1)	SOME (2)	PRONOUNCED (3)
1 YAWN A LOT			
2 SALIVATE, SWALLOW			
3 BELCH, BURP			
4 SWEAT			
5 MALAISE			
6 SKIN PALLOR			
7 WEAKNESS, TREMBLING			
8 HEADACHE			
9 NAUSEA			
10 VOMIT OR GAG			
11 LOSS OF APPETITE			
12 CONSTIPATION			
13 LETHARGY			
14 SORE MUSCLES			
OTHER______			

B. OVERALL ENVIRONMENTAL RATINGS (MARK THE SCALE WHERE APPROPRIATE)

EFFECT ON YOUR WELL-BEING BY:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
PLEASANT	Very	(1)			
	Slightly	(2)			
NO INFLUENCE		(3)			
UNPLEASANT	Slightly	(4)			
	Moderately	(5)			
	Extremely	(6)			
INTOLERABLE		(7)			

INTERFERENCE WITH SHIPBOARD DUTIES BY:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
IMPROVEMENT	Much	(1)			
	Slight	(2)			
NO INFLUENCE		(3)			
INTERFERENCE	Slight	(4)			
	Moderate	(5)			
	Extreme	(6)			
INCAPACITATING		(7)			

C. SPECIFIC TASK INTERFERENCE (RANK THE DEGREE OF INTERFERENCE THAT THE ENVIRONMENT HAD ON THE TASKS BELOW: 0 = NEGLIGIBLE (1); 1 = MODERATE (2); 2 = EXTREME (3))

GENERAL FUNCTIONS:

EAT: HAND FOOD (SANDWICH)___; THICK FOODS___; LOOSE FOODS___;

DRINK: FROM CLOSED CONTAINER___; OPEN CUP___; POUR HOT COFFEE___;

READ: LARGE PRINT___; FINE PRINT___; FINE DIAGRAMS___; CALCULATOR READOUTS___;

WRITE: LARGE PRINTING___; SMALL PRINTING___; SCRIPT___; FINE DIAGRAMS___; PLOTTING___;

REST: RELAX, SNOOZE IN CHAIR___; SLEEP IN BUNK, UNRESTRAINED___; SLEEP IN BUNK, RESTRAINED___; GO TO SLEEP QUICKLY___; AWAKE REFRESHED___;

MOVE ABOUT: WITH HANDHOLDS___; UNAIDED___; CLIMB LADDERS___; DESCEND LADDERS___;

CARRY LOADS: WITH TWO HANDS___; ONE HAND___; UP AND DOWN LADDERS___;

LAVATORY: WASH HANDS___; TOILET--SITTING___; TOILET--STANDING___; SHOWER___; RAZOR SHAVE___; ELECTRIC SHAVE___;

RECREATION: CARD GAMES___; MODEL KITS___; SEWING REPAIRS___; TV___;

MISSION FUNCTIONS:

READ DISPLAYS: DIGITAL___; ON CRT___; ON METERS___;

CONTROL TASKS: SWITCHES___; PUSH BUTTONS___; KEYBOARDS___; STEERING___;

EXPERIMENTAL TASKS:

NAV. PLOTTING___; COLLISION AVOID___; MISSILE DETECT.___; CRYPTO___; ACUITY___; LOCK-OPENING___;

ECC. TRACKING___; 2-AXIS TRACKING___; KEYBOARD___; ELECTROMECHANICAL REPAIRS___;

Figure III-1. Habitability Evaluation Questionnaire (Version Used by July and August Teams)

As shown in Fig. III-1 and detailed below, all of the scales were ordinal and ranged from gross three-level (none/some/much) assessments of very specific items to carefully graded seven-point scales for evaluation of a general quality. Although they were not shown on the subject's forms, integer ordinal scale numbers (shown in parentheses) were used in reducing the logged scale markings. This was dictated by the large size of the data base, and it greatly facilitated data reduction and punched card coding. Integer values of 1 to N were used because a blank (e.g., from an omitted score) was counted as a zero by the program used. No assumption of linearity of these ordinal scales is assumed or implied, and (to the extent possible) we use non-parametric statistics in the analysis of such data. It is hoped that the sample forms included in the appendix will serve as the basis for a standardized set of rating scales with which to facilitate comparisons among various simulations and sea trials.

A primary objective of the habitability ratings was the determination of the progressive effect of motion, if any. Consequently, assessments were scheduled periodically throughout each run (as specified below, for each category). However, the schedules were not rigorously adhered to. To assure independence, each evaluation was made on a fresh form which was deposited in the mailbox upon completion. Questionnaires were collected once per eight-hour shift.

Description of, and results and discussion for, each category of evaluation in succession are now presented.

B. KINETOSIS

1. Description and Procedures

Kinetosis is the general term for the ensemble of visual or physical motion-induced symptoms of which motion sickness is the dominant syndrome. It was rated both "globally," in terms of degree of kinetosis, and "diagnostically" to identify specific symptoms. The overall Kinetosis Rating (Fig. III-1, Part A) is given on a six-level ordinal scale with level descriptors written in terms of the degree of malaise experienced, ranging from none; stomach awareness; mild, moderate, or severe nausea; to emesis or retching. The Rating numbers of 0-5 shown to the left of the marked line were carried over from Human Factors Research, Inc., previous experiments (e.g., Ref. 22) and facilitated subjects' verbal communication of their rating. (The data analysis levels of 1-6 are shown in parentheses.) As also shown in Part A, the diagnostic rating was based on the degree ("none," "some," "pronounced" or "much") to which fourteen common symptoms of motion sickness were noted. (These were derived from Ref. 23 with the help of Dr. M. McCauley of Human Factors Research, Inc.) The terms in the list of symptoms were originally chosen to be relevant, brief, and understandable. (Some were later revised on the basis of debriefing comments to be in even simpler terms.)

Formal Kinetosis Ratings were scheduled at 0.5, 1.5, and 6 hours after the beginning of motion for each subject, and at 4.0 hour intervals thereafter, except during a subject's regular sleep period. Ratings of the overall kinetosis were also logged in the Test Conductor's notebook and/or the Medical Officer's log from time to time, most often when a subject was experiencing symptoms. These are reported in detail in the Medical Report on Phase II (Ref. 18), by Dr. D. Thomas, et al.

2. Results and Discussion

a. Motion Intensity Parameter, σ_{MSI}

Prior to presentation and analysis of the kinetosis evaluations, we digress to establish a basis for quantifying the intensity of motion from a motion sickness standpoint. The concept of using a "Habitability Weighting Function" on the SES motion spectra to emphasize the motion-sensitive frequencies in assessing an effective run acceleration level is thoroughly discussed and examples shown in our early work on this program, Ref. 12, in which both motion sickness sensitivity and whole-body vibration sensitivity were combined. Since that early effort, the same concept has been applied, more appropriately to just the kinetosis-sensitive frequencies, by JHU Applied Physics Lab (Ref. 17) under the impetus of PMS-304 (Ref. 4), using the log normal functional fitting HFR's motion sickness data in Ref. 19. Noting that the "Motion Sickness Incidence (MSI)" (percent of riders sick in a given period, typically 2 hours), when plotted on log frequency vs. log MSI, forms a universal MSI Weighting Function independent of acceleration magnitude, the MSI Weighted heave intensity is computed as follows:

<u>For Power Spectral Densities</u>:

$$\sigma_{MSI} = \left[\int_{o}^{f_{co}} W_{MSI}^{2}(f) \; \Phi_{g_z}(f) \; df \right]^{1/2}$$

where:

σ_{MSI} = MSI-weighted heave acceleration (g's)

$W_{MSI}(f)$ = Motion Sickness Weighting Function at each frequency

$\Phi_{g_z}(f)$ = Power spectral density of heave acceleration (g^2/Hz)

f = Frequency (Hz)

f_{co} = Cutoff frequency for MSI, about 0.7 Hz

<u>For ISO-Type Acceleration Spectra</u> (rms g's in each 1/3 octave band)

$$\sigma_{MSI} = \left[\sum_{i=.1}^{.8} [W(f_i) \quad G_{1/3}^{rms}(f_i)]^2 \right]^{1/2}$$

where:

σ_{MSI} = MSI-weighted heave acceleration (g's)

$W(f_i)$ = MSI Weighting Function, at each ISO center frequency

$G_{1/3}^{rms}(f_i)$ = ISO Spectrum intensity at each center frequency (g)

f_i = .10, .125, .16, .20, .25, .31, .40, .5, .63, .80 (Hz)

Although it has not yet been validated for complex waveforms (being based on quasi-sinusoidal motions), the <u>MSI-weighted heave acceleration</u>,

σ_{MSI}, is adopted herein as a tentative, and best available, basis for correlating kinetosis evaluations. Computations of the MSI weighted acceleration have been made in Ref. 17 for the full SS 3, SS 4, and SS 5 cases, and these have been simply ratioed by the appropriate scale factor for the attenuated cases. (As shown in Vol. 2, Ref. 20, the command and measured heave spectra are so close in the motion sickness frequency range that the use of command PSD in lieu of measured PSD is justifiable.)

The grouped motion conditions are arranged in order of ascending σ_{MSI} in Table III-1. Also repeated from Table I-1 are the total rms acceleration, and a data analysis letter code, used for simplicity in several of the following tables. (The one-pump cases C and J were separately coded, should the velocity limit thereby imposed affect the evaluations as it does affect σ_{MSI} in the SS 5 case). By coincidence, the σ_{MSI} ranking is the same as the order of successive rows of the motion condition matrix.

b. Time Course of Kinetosis Ratings

Kinetosis ratings were closely spaced near the start of each run, enabling the time course of kinetosis to be roughly plotted. To the formal ratings were added a number of verbally transmitted ratings transcribed from the Test Conductor and/or Medical Officer's logs, which were especially helpful in the terminal stages of motion sickness (severe nausea or emesis), and in evaluating who quit the cab on this account and when that occurred.

Before looking at the cluttered summary plots, consider Fig. III-2 which depicts the range typical time courses of Kinetosis Rating. In this severe motion condition, Full SS 5, one subject was sick and quit within 0.5 hour; one subject felt only little stomach awareness in the first 10 hours, then progressed suddenly to emesis within a 1 hour period but hung on for another 6 hours (while retching repeatedly) before quitting; while a third subject reported no symptoms whatever for the full 48 hour run. With such an intrinsic lack of consensus in the time course of kinetosis, it is difficult to establish any meaningful motion sickness time trends. One must revert, as HFR has been forced to do in its basic research, to the percentage of a large population that reaches emesis in a given period.

TABLE III-1

CONDITIONS ARRANGED BY MOTION SICKNESS INCIDENCE (MSI) WEIGHTED HEAVE ACCELERATION

CONDITION		ANALYSIS CODE*	TOTAL RMS G_Z σ_{gz} (g)	MSI WEIGHTED RMS G_Z† σ_{MSI} (g)
Static	—	A	0	0
Low (2/3)	SS 3	B	.13	.021
Medium (4/5)	SS 3	C, D	.16	.026
Full (1)	SS 3	E	.19	.032
Low (2/3)	SS 4	F	.17	.048
Medium (4/5)	SS 4	G	.19	.054
Full (1)	SS 4	H	.25	.071
Low (2/3)	SS 5	I	.19	.076
Full (1)	SS5	J	.25	.100
		K	.28	.113

*This code was used for computerized data-sorting. Conditions coded "C" and "J" were one-pump variants of the medium SS 4 and full SS 5 conditions, respectively (normally, the MoGen is driven by two pumps).

†Adapted from Table 2 of APL/JHU Report SES 013 (Ref. 17).

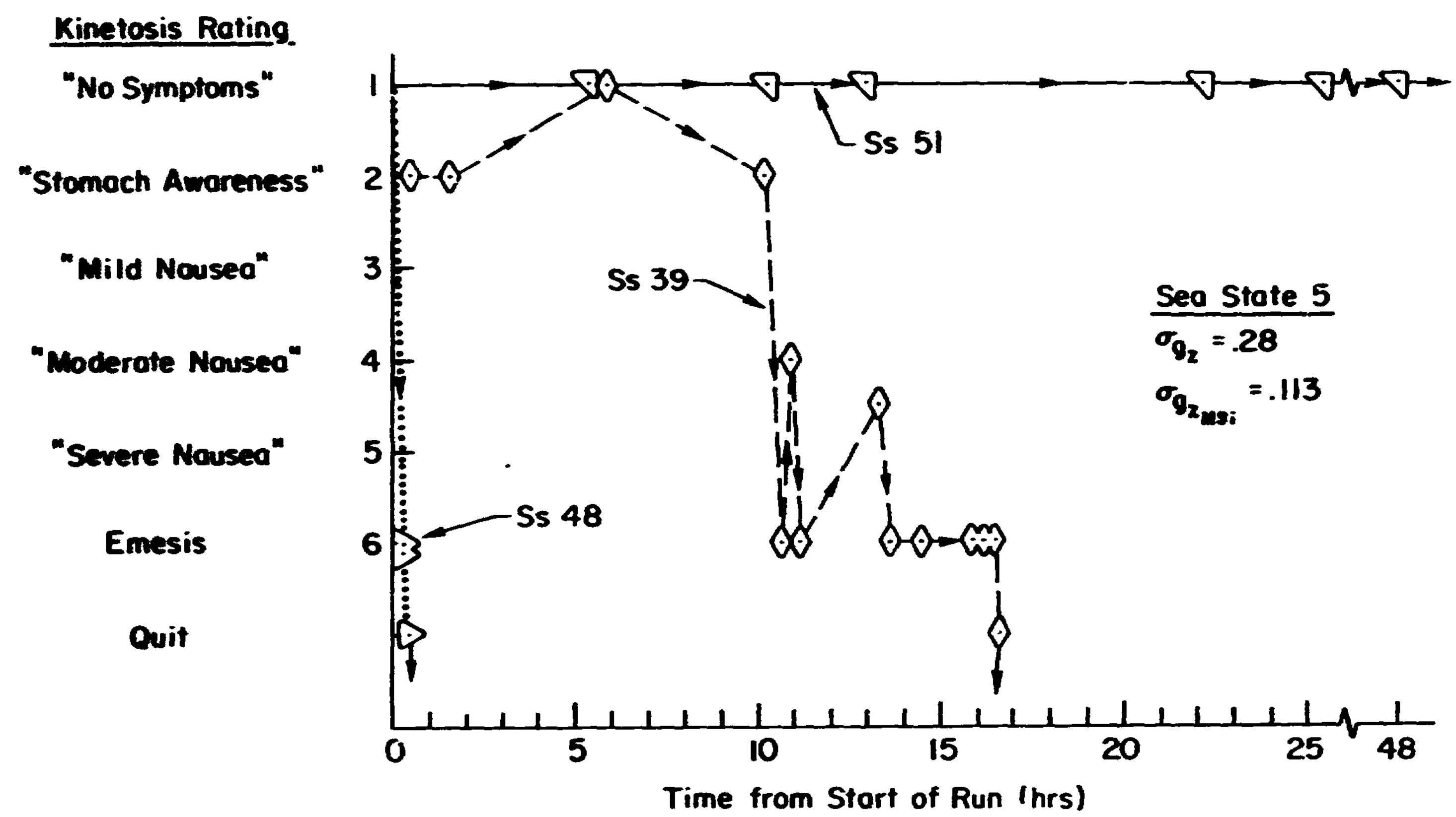


Figure III-2. Typical Variations in Time Course of Kinetosis

Since an average of such varied kinetosis ratings is meaningless, we have taken the worst rating by each subject within a given run as a measure of the ultimate kinetosis effect of that motion. The basic results for all cases logged are given in Table III-2 with columns arranged in order of increasing MSI-weighted acceleration, and 6 hour runs shown separated from the longer runs. The ratings are coded according to the 1-6 scale noted in Fig. III-2; those denoted by a dagger were culled from the Run Logs. The additional code letter E denotes "Emesis" and Q denotes "Quit" (one does not always accompany the other). In several cases ratings of 1-3 were followed suddenly by emesis, so that no progression in ratings was logged.

The percentages* at the bottom of Fig. III-2 indicate that 0 of 4 subjects logged were sick at the low SS 3 condition (σ_{MSI} = 0.021 g), but 5 out of 9 subjects were sick enough to quit at the next highest condition, Medium SS 3 with σ_{MSI} = 0.026, only 20 percent higher from an MSI standpoint. Such a sharp increase in MSI seems unlikely to represent the true trend, but as in some of the performance data there appears to be a sort of threshold effect operating here, such that if σ_{MSI} is below some level — about 0.025 g — kinetosis effects drop sharply. (The corresponding total rms G_z is about 0.15 g.)

At the higher sea conditions (Medium and Full SS 4 and SS 5), the various percentages of Table III-3 indicate that roughly one-third to one-half of each team were sick or quit due to kinetosis. None of the individual percentages means very much because of the small number of subjects tested at any condition and because only the more kinetosis-resistant crewmen survived to run at higher sea states. However, the consensus is clear: at conditions where the MSI-weighted rms acceleration was greater than about 0.05 g (whose total rms acceleration was above 0.19 g), a large fraction (from 1/3 to 1/2) of the crewmen were sooner or later incapacitated by motion sickness.

A graphical plot of all these worst ratings is given in Fig. III-3, versus σ_{MSI}. The wide range at any given σ_{MSI} supports the points made above that,

*The percentages shown were somewhat arbitrarily taken as a percentage of the subject-runs at a given condition, in the context of crewman-missions, as would be operationally meaningful (e.g., Medium SS 3 has 7 subjects, but 9 subject-runs, due to repeat encounters by a few subjects).

TABLE III-2. SUMMARY OF WORST KINETOSIS RATINGS*

		SUBJECT $\sigma_{g_{zv}}$	CONDITION							
			SEA STATE 3			SEA STATE	SEA STATE 4		SEA STATE 5	
			LOW .021	MEDIUM .026	FULL .032	LOW .048	MEDIUM .054	FULL .071	LOW .076	FULL .113
L† O N G	July	49		2, 4†		1		5† EQ		
		38		2, 5† Q		3				
		52		2				5.5† EQ		
		46		5† Q		5†				
		47		5 EQ		4† EQ		5; 3† EQ		
		44		1 EQ						
		35		2						
R U N S	Aug	50	2		3					5† Q
		39	1		2					4.5† EQ
		48	1‡		4 EQ					2† EQ
		58								4† EQ
		43	2		1					2, 1
		51			1					2,1
	Sept	60			1			4 EQ		
		61			1‡					
		56			2‡					
		40			2			4 EQ		
6 HR RUNS	Sept	60					1	1	2	1
		61					3 EQ			
		56					2		3 EQ	
		40					5	5†	1	5† EQ
		43					2	1	2	2
		39					1 E		1 EQ	
		57					5† EQ			
		51					2†	1	2	1
		% of Emesis	0	22	11	25	38	50	33	33
		% of "Quit"	0	44	11	25	25	50	33	42

Note: E indicates occurrence of emesis. Q denotes that subject quit (voluntarily terminated the run before its scheduled end).

*Per run by each subject. Commas separate given subject's data for two runs at same condition.

†Rating given verbally and recorded in Test Director's and/or Medical Officer's logs.

‡Ratings shown were given during first 24 hours of run; for the 3 data so marked subject's worst rating for the whole run was double that shown and was given after 25.5 hours (Subject 48) at low SS 3, and 34 hours (61) and 46 hours (56) at full SS 3.

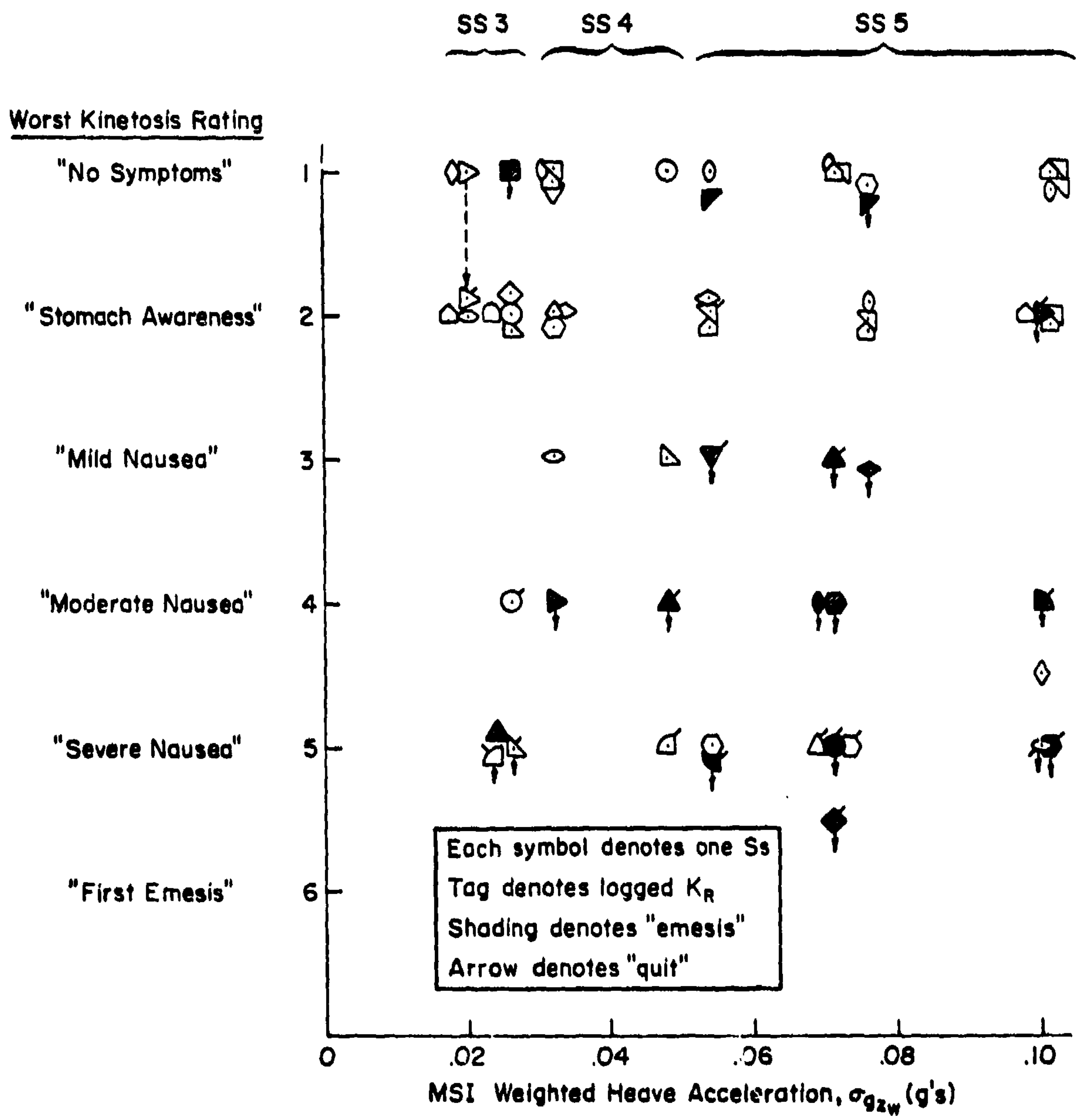


Figure III-3. Worst Kinetosis Rating vs. MSI-Weighted Heave Acceleration for Each Subject-Run for the crews of Phase II at least, a meaningful average trend is hard to specify. Connecting the points for several subjects does show some tendency for an individual to have worse kinetosis at higher σ_{MSI}. A percentage of subjects sick (MSI) would be more useful here, but that would take many more subjects than could be run in Phase II.

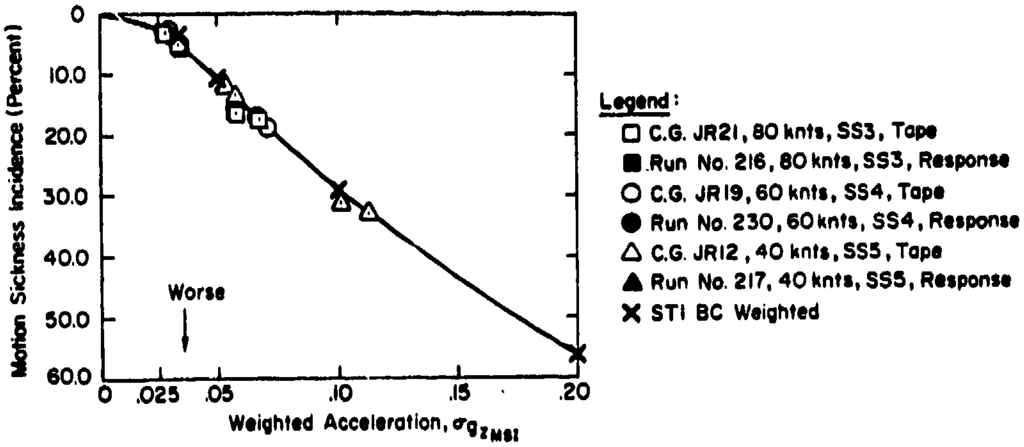
c. Evidence of Adaptation to Motion

One of the secondary objectives of Phase II was to look for evidence of adaptation to motion during long runs, as was experienced by two subjects in the Phases I and IA experiments (Ref. 6). Little such evidence was found, because most subjects who became sick quit the experiment; there were few cases where only moderate Kinetosis Ratings persisted, and only a few intrinsically kinetosis-resistant crewmen progressed to severe conditions.

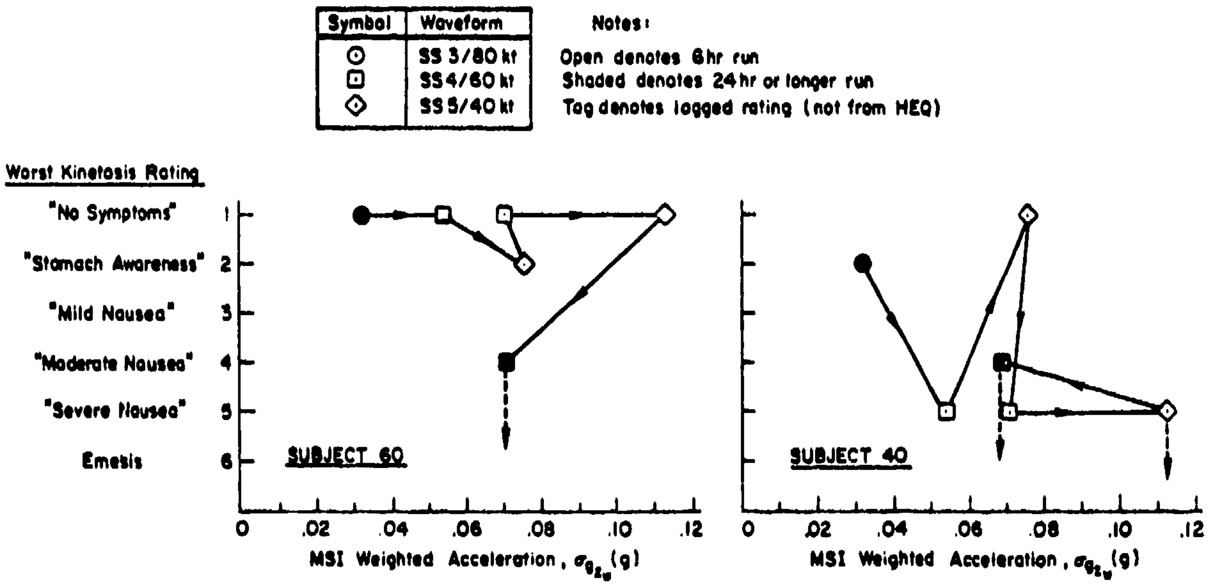
What evidence there is of adaptation is given on Fig. III-4. At the top is a plot of the HFR Motion Sickness Incidence (percent sick in 2 hours) vs. MSI-weighted heave acceleration (adapted from Ref. 17) to show the expected trend in kinetosis vs. σ_{MSI}. In the second row are the worst Kinetosis Ratings during successive runs of those two (out of four) subjects who experienced the most conditions and who were unable to tolerate SS 4 or greater and who eventually quit. The third row is ratings for the other two subjects, who were kinetosis resistant. The arrows connect the sequence of conditions experienced. Those segments which progress downward with increasing σ_{MSI} ($\searrow$) follow the trend expected from the MSI vs. σ_{MSI} plot at the top, while those segments which progress upward ($\uparrow\nearrow$) show evidence of adaptation upon successive encounters with more severe motion.*

Allowing for the precipitous improvements between SS 4 and SS 5 encounters, there are about five segments out of the twenty or so shown which show such an improving trend with successive encounters, and these are mostly for the mild ratings. Thus, there is some, but very meager, evidence for adaptation to successive motion encounters in a few of the subjects for which relevant data exist.

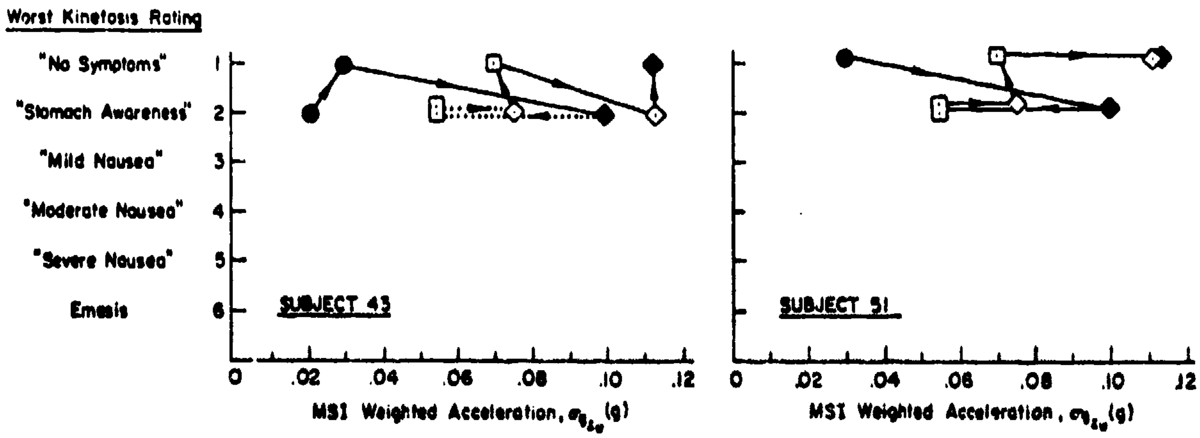
*The reader is cautioned that increasing MSI (percentage of sick subjects) does not necessarily imply a worse Kinetosis Rating for any given subject; but there is a rough correlation.



a. Trend of Motion Sickness Incidence (MSI) with Weighted Acceleration for Sinusoidal Motions (Adapted from Ref. 17)



b. Subjects Unable to Tolerate SS 4



c. Subjects Experiencing SS 5 Without Difficulty

Figure III-4. Worst Kinetosis Ratings for the Sequences of Conditions Encountered by Four Most-Tested Subjects

The problem of adaptation is an acute one for experimenters in motion sickness problems (Ref. 24) and deserves separate experiments and more analysis of the type attempted here.

d. <u>Terminal Phases of Kinetosis</u>

The large number of Kinetosis Ratings versus time, plus the logged ratings and emesis times, permit an interesting analysis of the course of severe motion sickness in those subjects who vomited or quit. First consider the time course of Kinetosis Ratings from the start of each motion condition, for SS 3, SS 4, and SS 5, for all those subjects who became severely nauseated or sick, as plotted in Fig. III-5. Besides the obviously wide range of trajectories described earlier, closer examination reveals the following trends:

- In the SS 3 conditions, it took more than 2 hours for 4 of the 5 "kinetosic" subjects to reach emesis, although several indicated moderate nausea within 2 hours. By 6 hours, 3 of 5 subjects had been sick.
- In SS 4, there is a wide range of trajectories with several showing some recovery for several hours after moderate or severe nausea, only to become sick again. In 6 hours, only 4 of the 10 kinetosic subjects had become sick.
- In SS 5, all but 2 of the 5 sick subjects had reached severe nausea in 2 hours, and all but 1 had been sick by 3 hours.

The pattern which emerges from this is that in SS 3 and SS 4 the crewmen got sick more gradually and intermittently than in SS 5. A second implication is that <u>6 hour runs would only catch about half of the potentially sick crewmen in SS 3 and SS 4, but almost all of them in SS 5</u>.

Noting the precipitous trend of motion sickness ratings just before emesis, we replotted the data of Fig. III-5 in terms of time-before-first-emesis, as shown in Fig. III-6. This illustrates the terminal phases of motion sickness. For those who vomited (shown at the top) there is a clear suggestion of a divergent trend from "no symptoms" or "stomach awareness" to emesis with a time constant of 2 to 4 hours for most subjects. However, a few showed a more gradual dropoff, some hanging on at moderate nausea for several hours; so the precipitous drop syndrome is not universal.

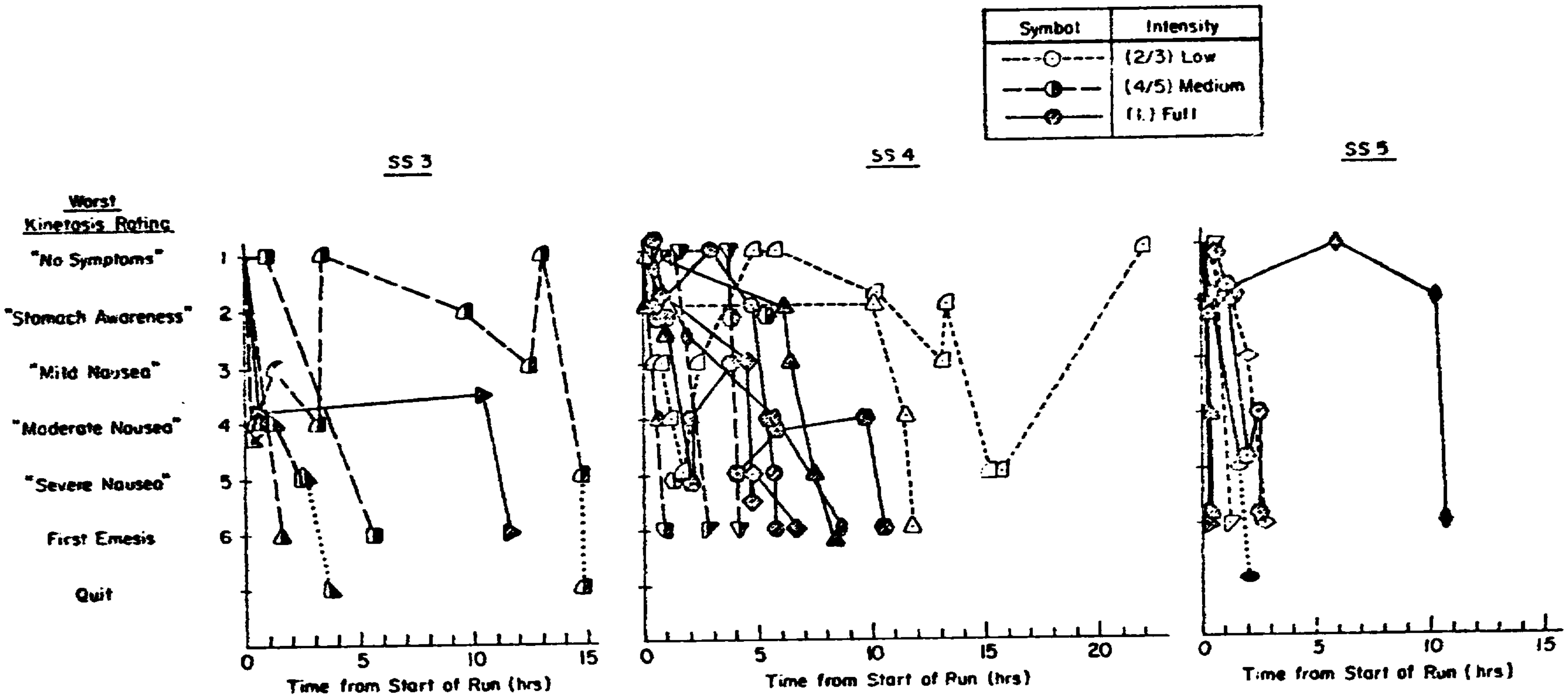
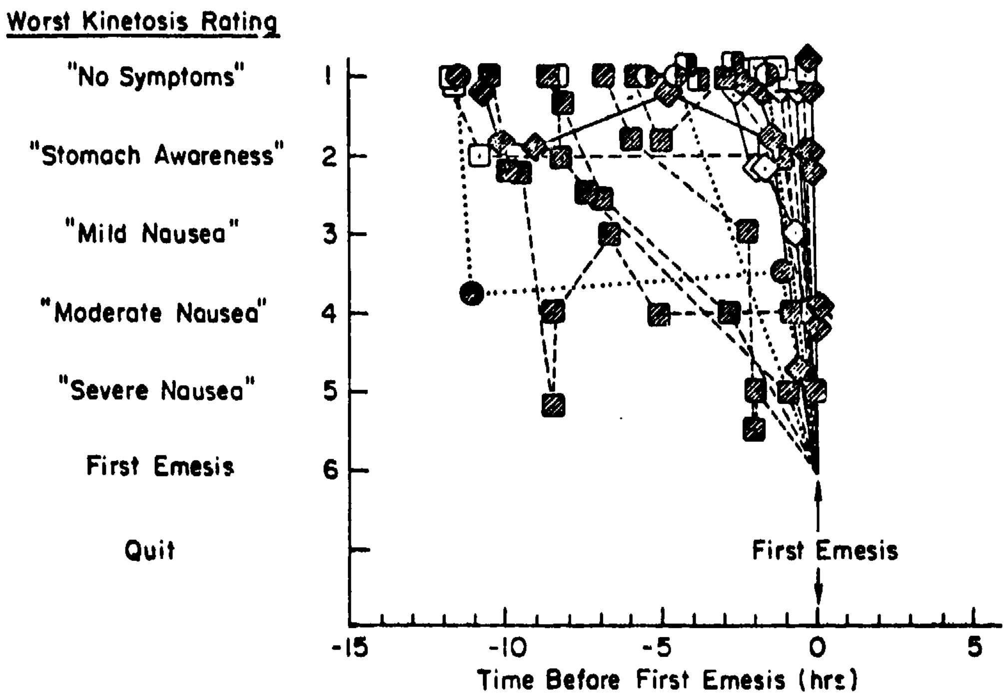
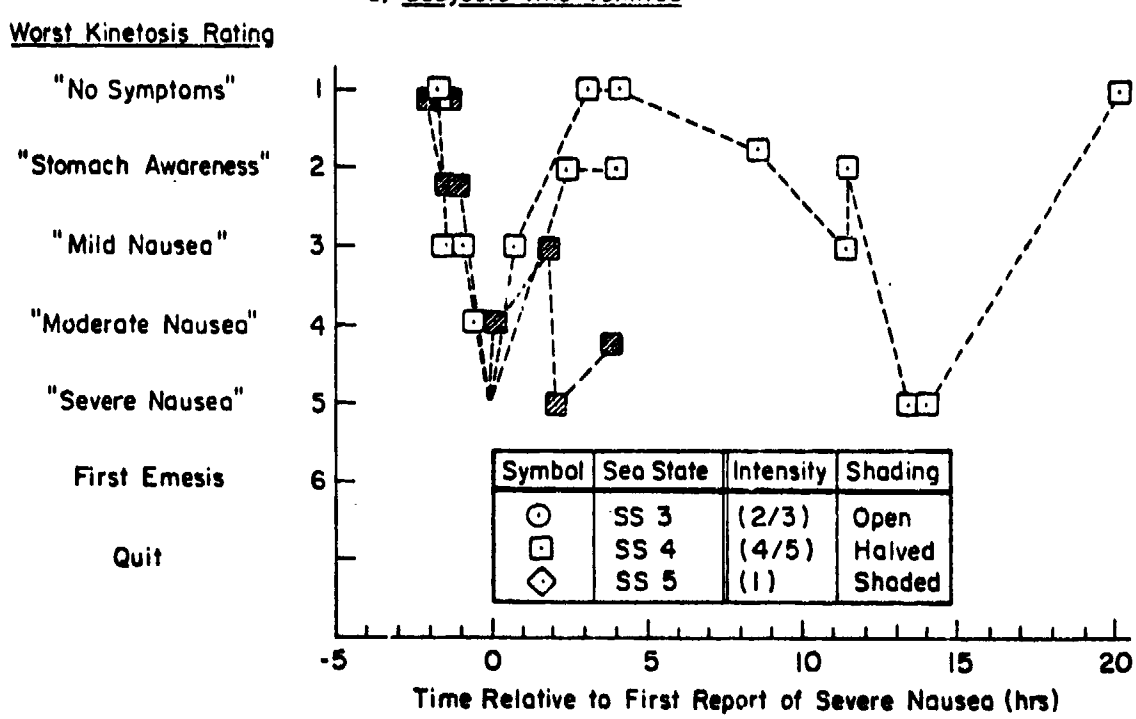


Figure III-5. Time Course of Kinetosis for Those Subjects Who Became Severely Nauseated or Vomited



a) Subjects Who Vomited



b) Subjects Who Reported Severe Nausea But Did Not Vomit or Quit

Figure III-6. Time Course of Kinetosis Relative to First Emesis or Severe Nausea

Even those few subjects who reached severe nausea (Level 5) without emesis had a similar trend up to that point as illustrated at the bottom of Fig. III-6. The one subject who recovered from the brink of emesis twice showed the same progression in both instances.

Although too meager to more than suggest possible trends, these data have application to the timing of Kinetosis Ratings in future experiments and in providing hard data for models of the dynamics of kinetosis to match.

e. Most Frequent Kinetosis Symptoms

The second portion of the Kinetosis section of the Habitability Evaluation Questionnaire (Fig. III-1) asked the subject to check their tendency (none, some, pronounced) to experience some fourteen symptoms previously found common in motion sickness research. A compendium of the replies is given in Table III-3. The symptoms have been paraphrased along the top, and each letter-coded motion condition eliciting a "some" (lower case) or "pronounced" (capital letter) symptom is identified by the appropriate letter (see Table III-2 for the code). To the right of these symptom data are given the worst Kinetosis Rating for the various letter-coded conditions, for correlation purposes.

The following observations are drawn from the symptom survey in Table III-4:

- There is no strong tendency for certain symptoms to be correlated with certain conditions, i.e., no particularly worse or more severe symptoms occurred at more severe MSI conditions (i.e., Conditions G, H, K).

- Some symptoms were experienced more commonly than others. Taking each subject in Table III-4 as a "subject," whether he be on a long or short run, and considering experience of the symptom at any condition an "instance," the symptoms ranked as follows, in order of descending occurrence:

(see page 115)

TABLE III-3. SUMMARY OF KINETOSIS SYMPTOMS REPORTED AT SOME TIME DURING CONDITION

[Note: Letters denote conditions, per Table III-1, during which presence of symptoms were reported, with lower case letters indicating "some" and upper case "pronounced" or "severe."]

			SYMPTOMS														WORST DEGREE OF KINETOSIS DURING GIVEN CONDITION									
		SUBJECT	1 YAWN	2 SALIVATE	3 BELCH	4 SWEAT	5 MALAISE	6 PALLOR	7 WEAKNESS	8 HEADACHE	9 NAUSEA	10 VOMIT	11 ANOREXIA	12 CONSTIPATION	13 LETHARGY	14 SLEEPINESS	S	C	D	E	F	G	H	I	J	K
		49	C, D, F, H	C, D, F, H	C, D, F, h					d						c		2	4		1		6			
L		38	c, f		c					d	c, d, f		f					2	5		3					
O		52	c		c, h		c			C, h	c, H	h	C, H	h		c		2					6			
N	July	46	d, f	d, f	d, f	d	f			D, f	d, f		f			D, f			5		5					
G		47	c, f		C, F	C, h	c	c, h	c, h	c, f, h	C, f, h	c̄			e			6			6		5,6			
		44		c	c		c								e			1								
		35	d							d									2							
R		50	b, e	b, e	b, e	b				b, E	e						2			3					5	
U		39	b, e	e, j	b, e, j	j			j		j	j	j				1			2					6	
N		48	B							b	b						2			6					6	
S	Aug	58							No HEQ filled out																6	
		43	b	b, e						b							2			1					2	1
		51	e		j															1					2	1
		60	E, H	h	h		e, h			h	h	h	H		h	e				1			6			
	Sept	61	e							e										2						
		56	e	e	e		e				e		e		e					4						
		40	e, H	e, h	e, h		e, h			e, h	h		e, h							2			6			
6		43	g, h, i, k	g, k																		2	1	2		2
H		51																				2	1	2		1
R		60	g, i	i	h, i																	1	1	2		1
		61	g							g					g	g						5				
R	Sept	56	i	g, i	g, i		i				I				g, i							2		6		
U		40	g, h, k	g, H, k	g, h, k	G, h, k	G, h, k	g		g, h, k	G, h, k	k	G, h, h		g							5	5	1		6
N		59								g, i		g										6		6		
S		57		g	g	g	g	g	g		g	g			g							6				

Self-Reported Symptoms: Coded Order	Descriptor	Percent of Subjects Reporting "Some" or "Pronounced" Degrees	
1	Yawn a lot	80	
3	Belch, burp	64	
8	Headache	56	By more than
2	Salivate, swallow	56	half of subjects
9	Nausea	52	
5	Malaise	40	
13	Lethargy	32	
11	Loss of appetite	32	
10	Vomit*	(28)	(Belongs higher)
4	Sweat	24	
14	Sore muscles	20	
7	Weakness, trembling	12	
6	Skin pallor	12	
12	Constipation	4	

*Vomiting was usually not reported on the forms once a subject vomited, because he was incapacitated or quit.

The low ranking of "skin pallor" may be due to the self-reporting of symptoms, whereby skin pallor of the face (the most common locale of pallor in motion sickness) was not perceived. Other reasons to be cautious in using these results are the crude definition of the percentages, the non-uniformity of sampling (where only a few subjects experienced severe sea states), and the pooling of all conditions in the evaluation of "instances." The reader can analyze Table III-4 any number of ways for his particular purpose.

- "Severe" symptoms were reported at some time by only 9 of the 25 subjects, and only mild correlation with the motion severity is apparent (about half the "severe" ratings were given under Conditions G-H, wherein $\sigma_{MSI} > 0.05$). As noted before, the severe nausea and vomiting experienced by most subjects seldom was reported on the formal questionnaires because they were incapacitated or had left.

- There is a weak correlation between reported Kinetosis Rating and symptom frequency, i.e., in most of the cases with Kinetosis Ratings of 6 there were from 5 to 9 symptoms reported in each case.

- Several attempts were made to cross correlate these nominative-scaled evaluations with motion severity, etc., but most of these were fruitless because of anomalous or missing data (e.g., lack of reported vomiting, though logged by the Test Director). Further, the forms were not always filled out carefully or completely, thereby greatly diluting the data base and, perhaps, biasing it in an unknown manner.

3. Specific Findings and Conclusions

The Kinetosis Ratings made at prescribed times or logged by the Test Conductor or Medical Officer showed the following trends:

- Roughly one-third to one-half of each team became sick or quit due to motion sickness in the various SS 4 or SS 5 conditions, where the MSI-weighted rms heave acceleration, σ_{MSI}, exceeded about 0.05 g (corresponding to roughly more than 0.20 g rms, total). No emesis occurred in the few cases of low SS 3, where $\sigma_{MSI} = 0.02$ (total $\sigma_{g_z} = 0.13$).

- The correlation of worst Kinetosis Ratings during a run with σ_{MSI} was broadly scattered but not inconsistent with the trend of MSI vs. σ_{MSI}.

- There was evidence of a more gradual kinetosis progression in SS 3, a pronounced drop in SS 4, and a precipitous drop in SS 5. Six-hour runs would expose only about half of the potentially sick subjects in SS 3 and SS 4 but almost all in SS 5.

- The time course of terminal motion sickness towards emesis varied widely among sick crewmen, with a common tendency to have mild symptoms followed by a divergent drop to "severe nausea" or "emesis" levels with a 2-4 hour time constant.

- There was meager evidence for some adaptation to successive motion conditions by a few subjects who experienced enough conditions to yield relevant data.

The evaluation of symptoms of kinetosis revealed that in these self-reported (often incompletely) cases:

- The most commonly experienced symptoms were: "Yawn a lot (80%); "belch or burp" (64%); "headache" (56%); "salivate, swallow" (56%); and "nausea" (52%). (Vomiting was incompletely reported on the forms because subjects were incapacitated or had quit.)

- Only vague and weak correlations could be detected between severity of motion (i.e., σ_{MSI}) and symptom frequency, but part of this problem was due to the incomplete or anomalous nature of some data.

It is concluded that the kinetosis evaluations show a clear consensus that from one-third to one-half of a group of crewmen such as these (with little sea experience) would, within several hours, experience severe nausea or become sick in conditions where the MSI-weighted rms heave acceleration exceeds about 0.05 g (roughly, total G_z rms > 0.19 g with appreciable content below 0.6 Hz). Below σ_{MSI} = 0.02 g, few would be affected. This conclusion impacts the design of heave alleviation systems and operating conditions. A small percentage of crewmen were intrinsically kinetosis resistant and had good performance under severe motion conditions. They provide evidence that an SES could be operated in severe sea states, without heave alleviation, albeit with a small select crew.

These kinetosis results are somewhat less optimistic than the Phases I and IA results (with experienced, motivated crewmen), and may in fact be unduly pessimistic because the naive crewmen tested were not typical of near-future SES crews.

Other, more diagnostic, medical and stress aspects of the crew's kinetosis can be found in Vols. 4 and 5 (Refs. 19 and 18).

4. Recommendations

We recommend using a standardized version of the final Kinetosis Evaluation Form for future SES habitability investigations, both in simulators and at sea. We feel that the basic form and procedures are sound, but that fill-out procedures need to be stricter. The forms must be more carefully filled out (via closer Test Director monitoring) to assure complete and valid data. In future simulations the basic kinetosis rating (KR = 1-6) should be verbally reported more frequently to more closely resolve the time course of kinetosis, especially towards its terminal (emesis) stage, where 0.5 hr resolution is required.

Better methods should be found to make non-parametric analyses of the large arrays of ratings vs. time, symptoms vs. conditions vs. ratings, and intercorrelations among them. A helpful detail would be to log all rating scales via integers from 1 to N (whether displayed to the subject or not) to facilitate data transcription and computerized data handling and tabulation.

C. REACTION TO VARIOUS ENVIRONMENTAL FACTORS

1. Rationale and Description

It was anticipated that under severe motion conditions or on very warm days various cabin environmental factors might become annoying or exacerbate any kinetosis tendencies. To check these possibilities, the influence of four relevant environmental factors — Whole Body Motion (low frequencies), Vibration (high frequencies), Sounds (in the cab), and Temperature (in the cab) — on the crewman's "sense of well being" and their interference with his ability to "perform shipboard duties" were rated every four hours. The ratings, which were to be made relative to the environmental conditions in the static cab, were made by checkmarks on a seven-point ordinal scale. This scale included an upward extension of the five-point scale used in Phases I and IA (Ref. 6) to include the possibility of beneficial as well as four adverse effects.

As noted on Fig. III-1B, the scales included the following categories:

- Effect on Well Being:

  Pleasant (Very, Slightly); No Influence; Unpleasant (Slightly, Moderately, Extremely); Intolerable.

- Interference with Shipboard Duties:

  Improvement (Much, Slight); No Influence; Interference (Slight, Moderate, Extreme); Incapacitating.

2. Results and Discussion

As events transpired, there were no serious complaints about any of the ambient conditions except whole-body motion. The bunk area of the cabin, being at the top of the room, tended to get warmer than desirable, but the vent fan helped remove this warm air. There is an appreciable amount of vibration and sound in the cab, mostly in the lower acoustic range of 25-100 Hz and due to the gear pump operating 10 feet away; however, these effects tend to mask other ambient sounds and provide a more SES-like environment because they are in a range similar to the SES water jet pump sounds and vibrations. Further details are given in Section II of Ref. 20.

Not all crewmen carefully logged these ratings, and we suspect that some merely checked off all items the same (no influence) under most conditions. Nevertheless, the data are presented here for the record. As discussed in connection with the Kinetosis Ratings, only the worst environmental rating during a subject's run is evaluated in this presentation (in any case, these ratings did not differ much with time).

a. Influence on Well Being

The histograms of the influence on their sense of well being are given in Figs. III-7a, b, c. The several one-pump runs have been combined with their two-pump counterparts but these data are denoted by a + instead of the two-pump X's. On these histograms an "M" denotes the median rating, which can be considered as the "typical" rating because the histograms are fairly unimodal.

With few exceptions, the typical ratings for Vibration, Sound, and Temperature influence on crewmen's sense of Well Being were "No Influence" or "Slightly Unpleasant" throughout all test conditions. The histograms actually suggest a slight improvement with higher sea state, but this is probably due to the fewer, more tolerant subjects surviving to these conditions. Considering the widespread experience of severe nausea and emesis, the ratings of whole-body motion effects on the sense of well being are relatively mild. Only in Medium and Full SS 3 cases (Fig. III-7a) do ratings of Extremely Unpleasant appear at all, and the Median ratings are only Slightly to Moderately Unpleasant. We suspect that as in the Kinetosis Ratings some of those who were incapacitated simply could, or did, not log their environmental ratings.

We conclude that the environmental factors of Vibration, Sound, and Temperature did not have any serious influence on the crewmen's sense of well

NOTES: 1) EACH X OR + IS THE WORST RATING FOR "EFFECT ON YOUR WELL BEING BY:" DURING A RUN FOR 1 SUBJECT

2) M DENOTES THE MEDIANS

3) X = 2 PUMPS , + = 1 PUMP IN OPERATION

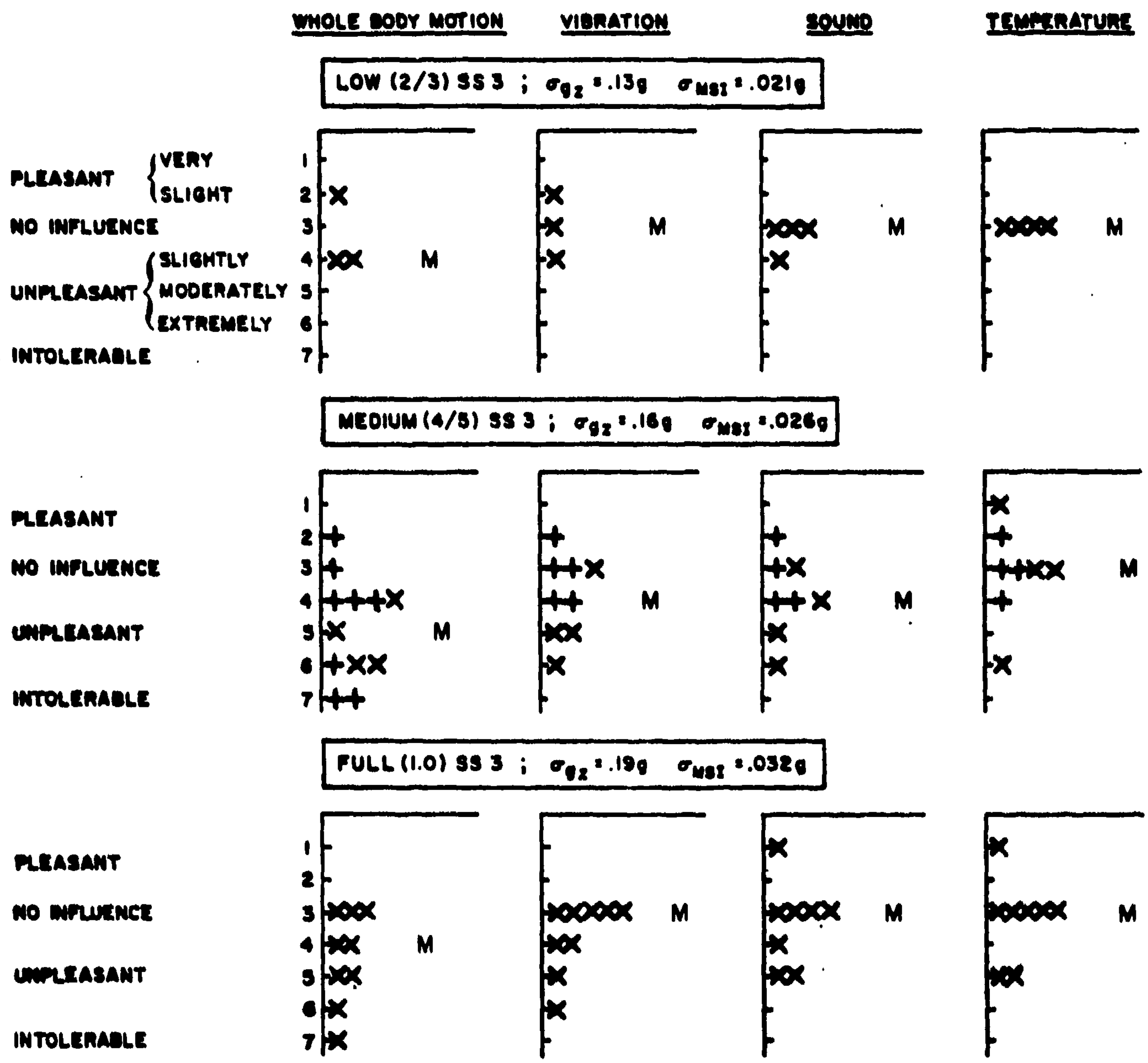


Figure III-7a. Environmental Ratings for SS 3 Conditions

NOTES: 1) EACH ✕ OR ✚ IS THE WORST RATING FOR "EFFECT ON YOUR WELL BEING BY:" DURING A RUN FOR 1 SUBJECT

2) M DENOTES THE MEDIANS

3) ✕ = 2 PUMPS, ✚ = 1 PUMP IN OPERATION

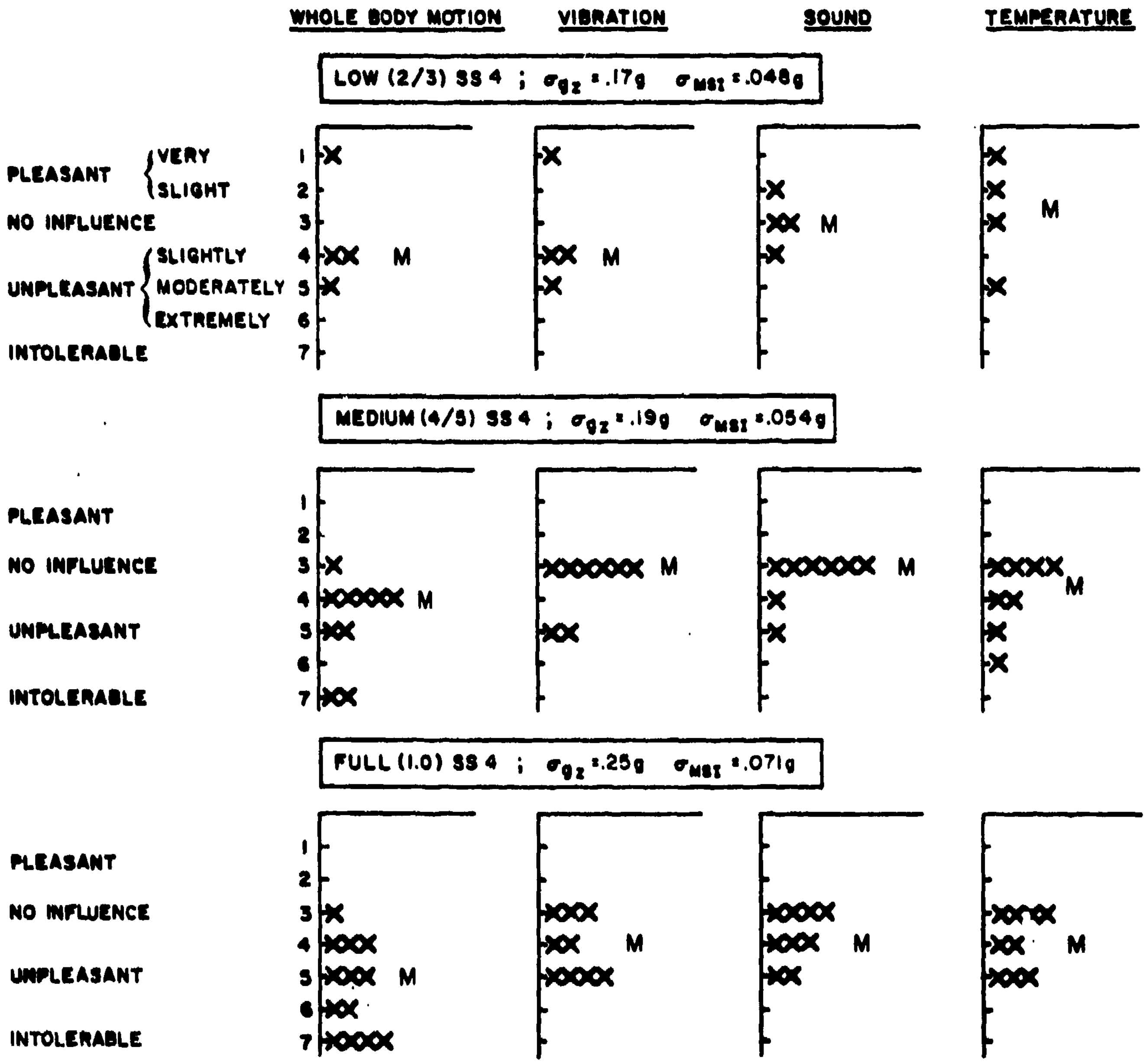


Figure III-7b. Environmental Ratings for SS 4 Conditions

NOTES: 1) EACH ✕ OR + IS THE WORST RATING FOR "EFFECT ON YOUR WELL BEING BY:" DURING A RUN FOR 1 SUBJECT

2) M DENOTES THE MEDIANS

3) ✕ = 2 PUMPS , + = 1 PUMP IN OPERATION

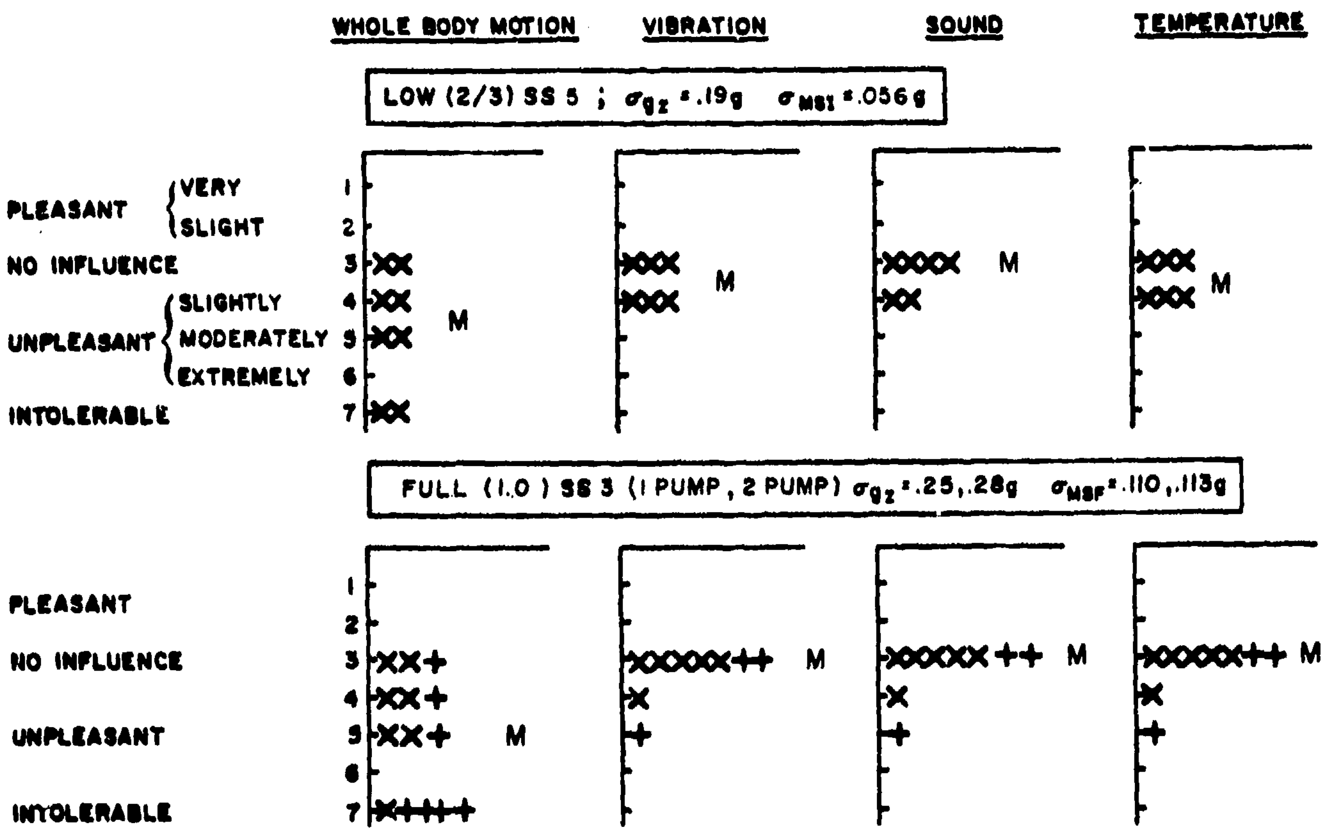


Figure III-7c. Environmental Ratings for SS 5 Conditions being during the Phase II tests. The ratings of Whole Body Motion must be considered suspect because they do not jibe with the more complete kinetosis data and actually improve at more severe motion conditions.

b. Interference with Duties

Next consider the ratings of environmental interference with shipboard duties, shown in Figs. III-8a, b, c. As was true for the effects on Well Being, the interference of Sound and Temperature on Shipboard Duties was negligible, the medians being between "No Influence" or "Slight Interference." Vibration is evaluated as having "Slight" to "Moderate Interference" for Medium SS 3 and Low SS 4 conditions, but most of the low ratings were traced to a few subjects.

As in the well being ratings, the whole body motions produced the largest effects and with similar trend of the median ratings. Interestingly, 7 out of 8 of the "Incapacitated" ratings (sometimes logged by the experimenter on the subject's unfilled form) were for the more benign one-pump runs as (4/5) SS 3 and (1.0) SS 5.

There are too few data to have a really sound median trend, and those at the higher sea states were biased towards the motion sickness resistant subjects. Consequently, we have not attempted any correlation of the Well Being or Interference ratings with total rms G_Z or σ_{MSI}.

D. INTERFERENCE WITH SPECIFIC TASKS

1. Rationale and Description

It would be useful to know the ease with which various types of shipboard functions such as eating, reading, lavatory, etc., can be carried out under each motion condition. A simple evaluation form was developed for this purpose during Phases I and IA and successfully applied (Ref. 6). An improved version of this interference evaluation form was included as Part C of the Habitability Evaluation Questionnaire (see Fig. III-1). It was divided into three broad categories of activity (computer code in parentheses):

NOTES: 1) EACH ✕ OR + IS THE WORST RATING FOR "INTERFERENCE WITH SHIPBOARD DUTIES BY:" DURING A RUN FOR 1 SUBJECT
2) M DENOTES THE MEDIANS
3) ✕ = 2 PUMPS, + = 1 PUMP IN OPERATION

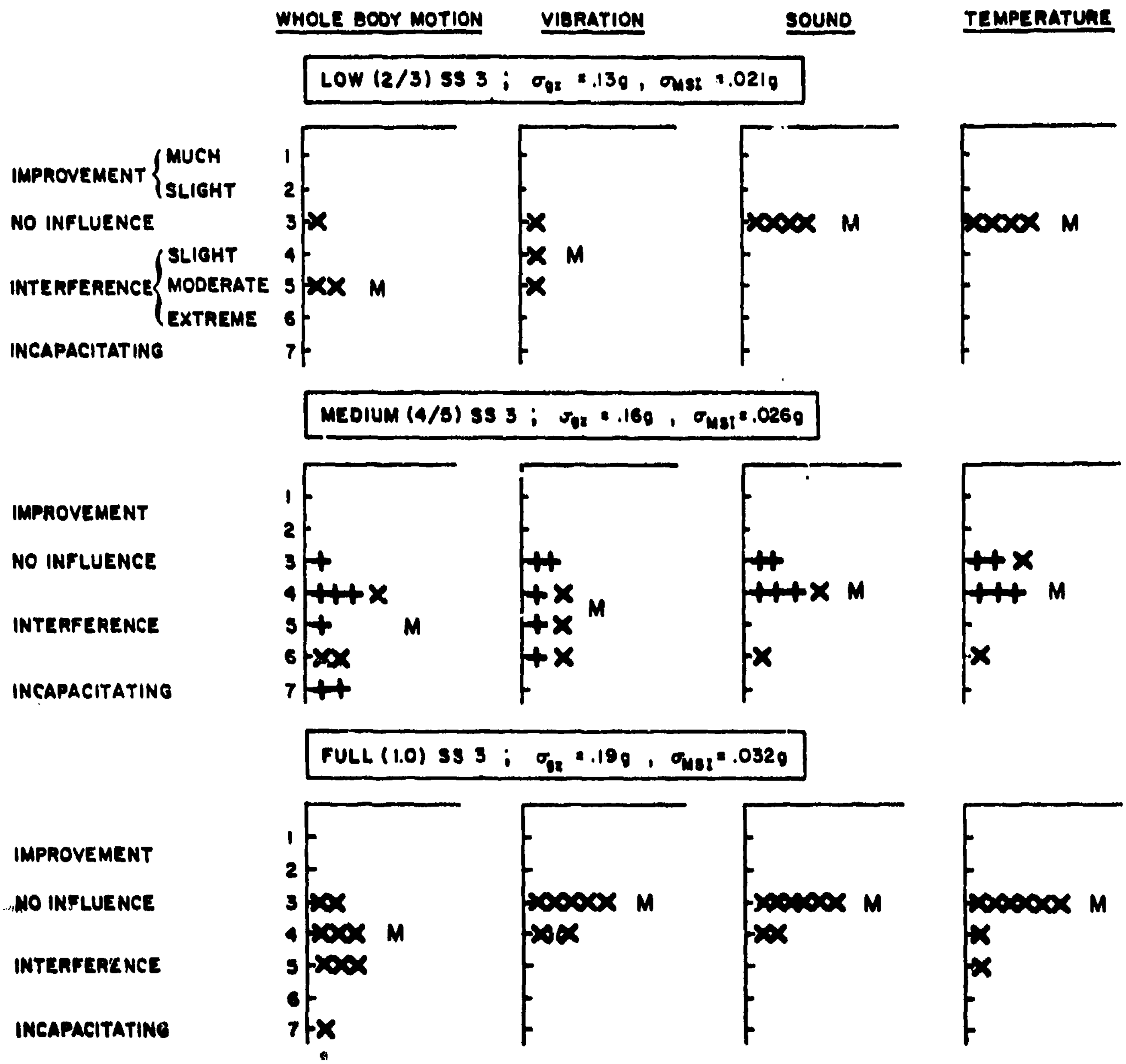


Figure III-8a. Motion Interference Ratings for SS 3 Conditions

NOTES: 1) EACH X OR + IS THE WORST RATING FOR "INTERFERENCE WITH SHIPBOARD DUTIES BY:" DURING A RUN FOR 1 SUBJECT

2) M DENOTES THE MEDIANS

3) X = 2 PUMPS, + = 1 PUMP IN OPERATION

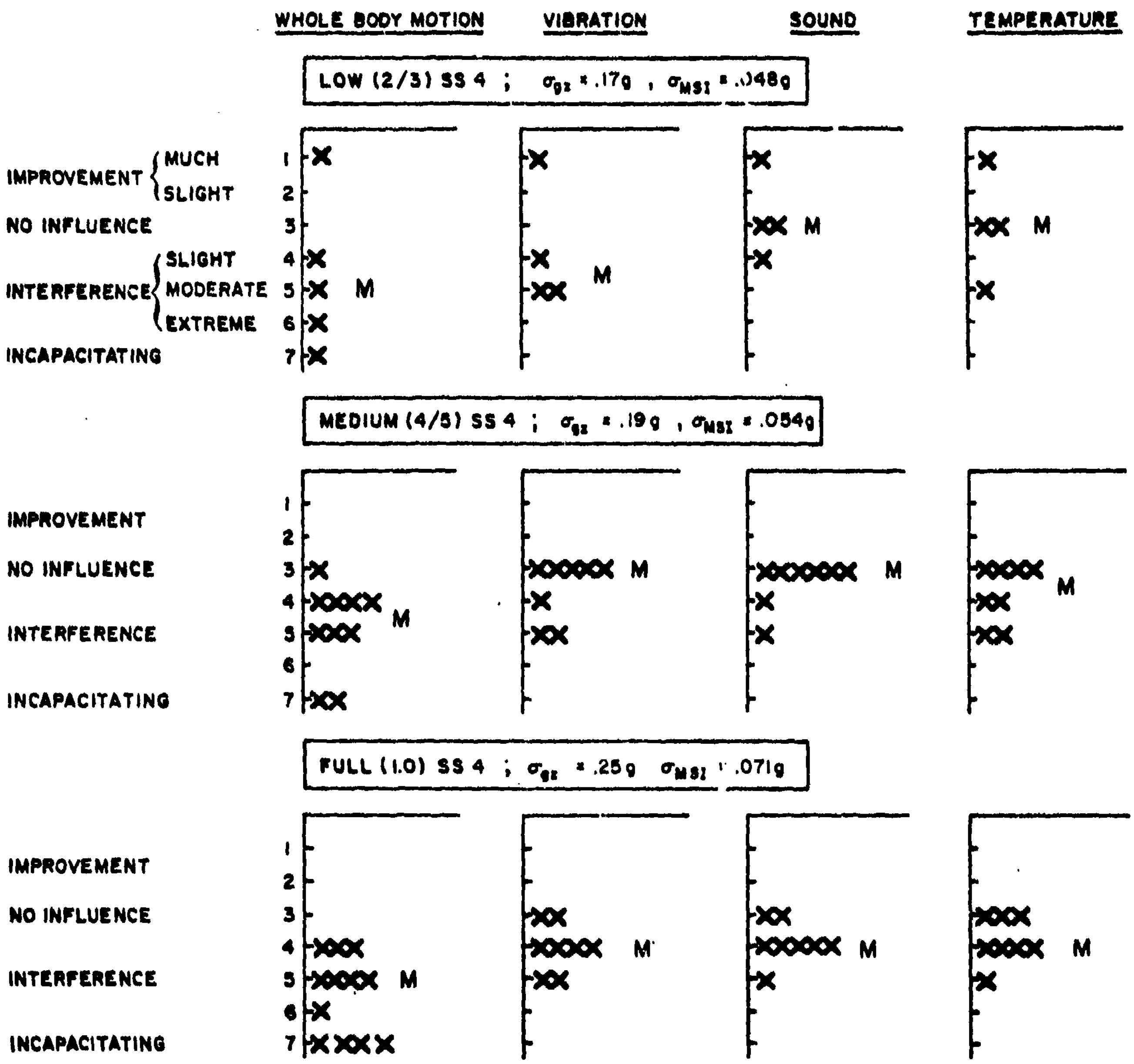


Figure III-8b. Motion Interference Ratings for SS 4 Conditions

NOTES: 1) EACH ✕ OR + IS THE WORST RATING FOR "INTERFERENCE WITH SHIPBOARD DUTIES BY:" DURING A RUN FOR 1 SUBJECT

2) M DENOTES THE MEDIANS

3) ✕ = 2 PUMPS, + = 1 PUMP IN OPERATION

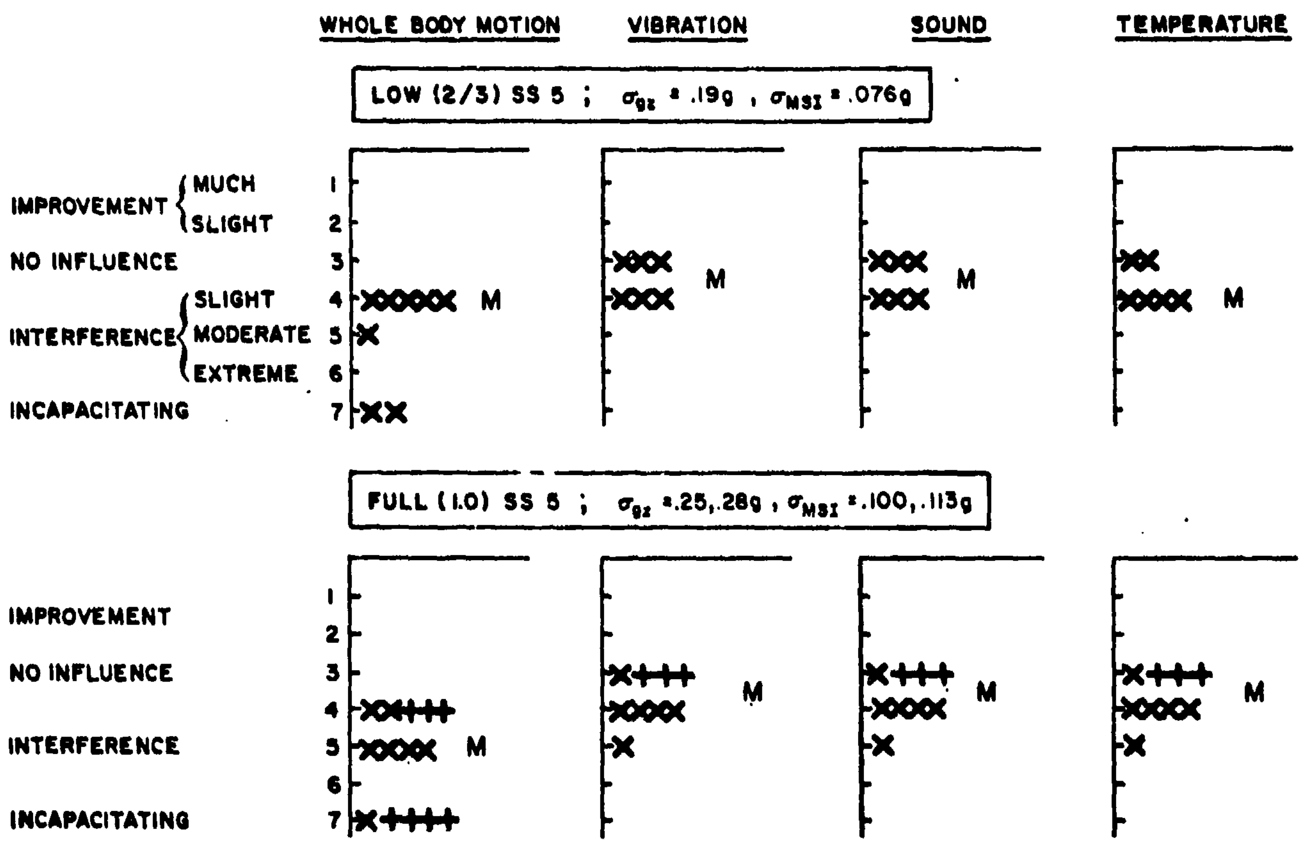


Figure III-8c. Motion Interference Ratings for SS 5 Conditions

- General Functions:

  Eat (EAT), Drink (DRINK), Read (READ), Write (WRITE), Rest (REST), Move About (MOVE), Carry Loads (CARRY), Lavatory (LAVATE), and Recreation (RECR).

- Mission Functions:

  Read Displays (VIS), Control Tasks (MANIP).

- Experimental Tasks:

  (EXPER TASK)

Within each above named activity were several subtasks of increasing difficulty under motion, e.g.,

Move About: with handholds__; unaided__; climb ladders__; descend ladders__

The subject was to evaluate the degree of interference that the motion environment had on each subtask as being: "Negligible" (1); "Moderate" (2); or "Extreme" (3)*. This ordinal rating scheme used evaluation numbers only for their (later) coding convenience. (In fact, during Phase IA the questionnaires read "Was the activity easy to do under motion? yes = √, maybe = ?, no = X.) Therefore, no relative weighting is to be assigned to the numbers.

The evaluation was scheduled at 1.5 hours and every 12 hours thereafter on long runs and at the end of each 6 hour run.

2. Results and Discussion

Unfortunately, due to various reasons, many subjects failed to complete Form C, and some who did were obviously not doing it carefully. Therefore, much of this potentially valuable information was lost, and what there is, is suspect in some cases (as for the SS 5 survivors who found no motion interference with almost anything). Furthermore, for several of the September runs, Form C (which had been put on a separate sheet to facilitate its once per day use) was inadvertently not given to the subjects by the Test Conductor, so these data were also lost. The upshot of all these problems is that only about half of the intended task interference data were obtained.

*The forms actually used 0, 1, 2 but had to be transcribed as 1, 2, 3 to avoid gaps being scored as zeros.

The raw data, tabulated from the HEQ forms (and, in cases of incapacitation often from the Run Logs), are presented in Tables III-4 for the General Activities and Table III-5 for the Mission Functions and Experimental Tasks. The lefthand columns of each table are for the various run, motion condition, and subject codes, as noted thereon. In the center, under each task code word given above (e.g., EAT, DRINK, etc.), are a group of numerals from 1 to 3, signifying the degree of interference. The order within each group corresponds to the subtask arrangement on Fig. III-1C. Thus, in Table III-5 under EAT for Record 1 (Run 483, Subject 50, Motion B = Low SS 3, IRIG Day 228 at 11:30 Hr), the subject scored "Negligible" interference with "Eat: hand foods (1), thick foods (1), or loose foods (1)." Blanks denote missing data. A similar format is used in Table III-6 with tasks coded as noted in an earlier paragraph. The last column, DDay $\equiv \Delta$Day, is the time from first formal run as used earlier in presenting the basic performance data.

We attempted to statistically analyze these data as was successfully done in Phases I and IA (Ref. 6); however, the data and subjects are so unevenly spread among conditions (e.g., too few at all SS 4 cases) to form valid and comparable statistics.

Some "gung ho" crewmen, notably Nos. 43 and 51, tended to just check everything hastily with a "1" when they felt good, even when in Full SS 5 where interference with many tasks was indeed moderate or severe.

Careful inspection of the HEQ forms and debriefing comments indicates that ratings of Subject No. 60 were more carefully made, seemed to repeat well upon successive evaluations, and are probably closer to the real situation than most. On the other hand, Subject 39's ratings seem highly erratic and often inappropriate when compared with other persons' evaluations (e.g., "Extreme" interference (3) with drinking from partially closed or open containers seems unlikely in Full SS 3 where he so rated it twice during Run 489). To dilute such idiosyncracies, data from many subjects at identical conditions are required.

TABLE III-4. TABULATION OF GENERAL FUNCTION INTERFERENCE RATINGS

GENERAL TASK INTERFERENCE: 1 = Negligible 2 = Moderate 3 = Extreme

RECORD REC	MOGEN RUN RUN	SS NO. SC	MOTION C	CONDITION INFO. MOT	DAY, NIGHT SCH	TRIG DAY HOUR DAY-HR:M	TEST CODE TC	HFR RUN EP	EAT	DRINK	HEAD	WRITE	WEST	MOVE	CARRY	LAVATE	PECP	DECIMAL DAY DAYTIM	FIRST DAY DAI	ΔDAY FROM START DDAY	CONDITIONS
1	483	50	A	H32	D12	228-1130	W1	12	111	111	1111	11111	11111	1111	111	111111	11 1	228.45	225	3.48	Low SS 3
2	483	50	A	H32	D14	228-2345	W1	12	111	111	1111	11111	11121	1111	121	111111	1111	228.99	225	3.99	
3	483	50	A	H32	D16	229-0800	W1	12	111	111	1111	11111	21111	1111	111	111111	1111	229.33	225	4.33	
4	485	39	B	H32	N16	231-2340	W1	13	222	22		2 2	11	1		2 2	1	231.99	228	3.99	
5	485	39	B	H32	N21	232-1137	W1	13	222	22	2	222	2		1	2	2	232.48	228	4.48	
6	485	39	B	H32	N24	232-2330	W1	13	211	222	22 1	3	22 2	3				232.98	228	4.98	
7	485	48	B	H32	D14	231-2340	W1	13	222	22		2 3	11133	11		222	1	231.99	228	3.99	
8	485	48	B	H32	D21	232-1137	W1	13	222	22	123	23 2	12	12	12	212		232.48	228	4.48	
9	485	48	B	H32	D23	232-2330	W1	13	111	222	123	12332	11233	11	11	222		232.98	228	4.98	
10	483	43	A	H32	N13	228-1130	W1	12	111	111	1111	11111	11111	1111	111	111111	1111	228.43	225	3.44	
11	483	43	B	H32	N15	228-2345	W1	12	111	111	1111	11111	11111	1111	111	111111	1111	228.99	225	3.99	
12	483	43	A	H32	D23	229-2305	W1	12	111	111	1311	11111	11111	1111	111	111111	1111	229.96	225	4.96	
13	439	52	C	R32	N13	200-2030	W1	03	222	32	1223	23233	2	1233	123	112		200.85	194	6.85	Medium SS 3
14	439	52	C	R32	N15	201-0845	W1	03	332	32	1222	12222	21 21	12		12		201.36	194	7.36	
15	439	47	C	R32	D12	200-2035	W1	03	222	223	2223	22332	3 32	2222	332		1	200.86	194	6.86	
16	440	49	C	R34	N11	201-1150	W1	04	1	1	1	2	1	1			1	201.49	191	10.49	
17	440	49	C	R34	N13	201-1950	W1	04		1	13	2	1	1		1	1	201.83	191	10.83	
18	440	49	C	R34	N14	201-2330	W1	04	111	1	3	3		1	1	1	1	201.98	191	10.98	
19	455	46	D	Q31	N15	210-2308	W1	09	112	133	1232	222 2	2	12		112 2	1	210.96	208	2.96	
20	457	49	D	Q35	N14	211-2324	W1	10	2	2						2		211.98	191	20.98	
21	525	60	E	M32	D12	259-1140	W1	19			1	22	1	12				259.49	256	3.49	Full SS 3
22	525	60	E	M32	D21	260-1115	W1	19	111	121	1221	11112	13332	1222	213	311121	1221	260.47	256	4.47	
23	525	60	E	M32	D23	260-2345	W1	19	111	121	1221	12122	12231	1211	211	111121	1221	260.99	256	4.99	
24	525	60	E	M32	D24	261-0350	W1	19	111	121	1221	11122	12221	1211	212	211121	1211	261.16	256	5.16	
25	525	40	E	M32	N12	259-1140	W1	19	21			2	2 2					259.49	256	3.49	
26	525	40	E	M32	N21	260-1115	W1	19	112	111	1211	12121	11112	1211	212	121121	1211	260.47	256	4.47	
27	525	40	E	M32	N24	260-2345	W1	19	111	121	1221	12121	11112	2 11	211	111121	1221	260.99	256	4.99	
28	487	50	E	M33	D13	234-2035	W1	14							1			234.86	225	9.86	
29	487	50	E	M33	D14	234-2330	W1	14	111	111	1111	11111	11111	1111	111	111111	1111	234.98	225	9.96	
30	489	39	E	M34	N22	238-2128	W1	15	111	33	1	1	11 1		11	1	1	238.89	226	10.89	
31	489	39	E	M34	N23	239-0915	W1	15	22	33	1		22	3		212	1	239.34	228	11.39	
32	487	43	E	M34	N12	234-1130	W1	14	11	2	11		1	11		1	1 1	234.48	225	9.48	
33	487	43	E	M34	N14	234-2035	W1	14							1			234.86	225	9.86	
34	487	43	E	M34	N15	234-2330	W1	14	111	111	1111	11111	11111	1111	111	111111	1111	234.98	225	9.98	
35	489	51	E	M31	D23	239-0915	W1	15	111	111	1211	12111	11111	1111	111	111111	1111	239.34	237	2.39	
36	453	46	F	M41	N15	208-2326	W1	07	111	12	1222	123 2		23	22	132	2	208.98	208	.98	Low (2/3) SS 4
37	454	47	F	M41	D12	209-1110	W1	08	2	1	1112	11112	22	12	11	111 2	1	209.47	194	15.47	
38	454	49	F	M41	N12	209-1121	W1	08	1	1				1				209.47	191	18.47	
39	454	49	F	M41	N15	209-2300	W1	08	1	1	1 3	1		1	1	1		209.96	191	18.96	
40	532	60	G	Q42	D14	266-1236	W1	23	111	122	1221	11112	22221	1211	213	311231	1321	266.53	256	10.53	Medium (4/5) SS 4
41	533	61	G	Q42	N14	266-1830	W1	24	111	222	22	11111	11111	1111	111	111111	1111	266.77	259	7.77	
42	532	56	G	Q42	D14	266-1236	W1	23	111	111	1111	11111	11111	1111	111	111111	1111	266.53	259	7.53	
43	533	57	G	Q41	N13	266-1830	W1	24	111	211	1211	11111	3 32	2	111	111111	1111	266.77	265	1.77	
44	540	60	H	M43	D15	269-1250	W1	29	111	122	1222	11122	23333	2322	323	111231	1321	269.53	256	13.53	Full (1.0) SS 4
45	541	40	H	M43	N15	269-2000	W1	30	111	112	1221	12112	12222	1111	211	21221	1221	269.83	256	13.83	
46	540	43	H	M43	D15	269-1251	W1	29	111	112	1111	11111	11111	1233	112	111211	1211	269.54	252	17.54	
47	541	51	H	M43	N15	269-2000	W1	30	111	11	1211	11	1	2	11			269.83	252	17.83	
48	539	60	I	M52	D15	268-1250	W1	27	111	112	1221	11122	13333	1222	213	111211	1321	268.53	256	12.53	Low (2/3) SS 5
49	535	43	I	M51	D15	267-1255	W1	25	1	12	1221	11111	11111	1222	112	111132	1221	267.54	252	15.54	
50	494	43	J	P51	N11	242-1130	W1	16		2	111	1	111 2	12		1 1	1 1	242.48	225	17.48	Full SS 5
51	494	43	J	P51	N13	242-2215	W1	16	1	2	11		111	11	1	111	1 1	242.93	225	17.93	
52	494	43	J	P51	N22	243-1200	W1	16	1	11	11	1	1111	11	11	111	1 1	243.50	225	18.50	
53	543	60	K	M53	D15	270-1304	W1	31	111	111	1221	11222	33332	3332	13	112311	331	270.54	256	14.54	
54	543	43	K	M53	D15	270-1305	W1	31	111	111	2111	11111	11111	1122	123	111111	1111	270.55	252	18.55	
55	547	43	K	M55	D21	273-1117	W1	34	111	111	1211	11111	11111	1222	222	111111.	1111	273.47	252	21.47	
56	547	43	K	M55	D25	274-0832	W1	34	111	111	1111	11111	11111	1111	111	111111	1111	274.36	252	22.36	
57	547	51	K	M55	N21	273-1130	W1	34	111	11	11 1	22 2	11122	2	11	1 1	1	273.48	252	21.48	
58	547	51	K	M55	N25	274-0832	W1	34	111	111	1111	11111	11111	1111	111	111111	1111	274.36	252	22.36	

TABLE III-5

TABULATION OF MISSION AND EXPERIMENTAL TASK INTERFERENCE RATINGS

RECORD REC	MOGEN RUN RUN	S_s NO. SC	MOTION C	CONDITION INFO. MOT	DAY, NIGHT SCH	IRIG DAY HOUR DAY-HR:M	TEST CODE TC	HFR RUN ER	MISSION AND EXPERIMENT TASK INTERFERENCE 1=Negligible 2=Moderate 3=Extreme VIS	MANIP	EXPER TASK	DECIMAL DAY DAYTIM	FIRST DAY DA1	ΔDAY FROM START DDAY	CONDITIONS
1	483	50	B	H32	D12	228-1130	W2	12	111	1111	1111111111	228.48	225	3.46	Low (2/3) SS 3
2	483	50	B	H32	D14	228-2345	W2	12	111	1111	111111111	228.99	225	3.99	
3	483	50	B	H32	D16	229-0800	W2	12	111	1111	1111111111	229.33	225	4.33	
4	485	39	B	H32	N21	232-1137	W2	13		222	33222	232.48	228	4.48	
5	485	39	B	H32	N24	232-2330	W2	13	2	222	233	232.99	228	4.98	
6	485	48	B	H32	D21	232-1137	W2	13	222	2222	332222	232.48	228	4.48	
7	485	48	B	H32	D23	232-2330	W2	13	111	2232	232332	232.98	228	4.98	
8	483	43	B	H32	N13	228-1130	W2	12	111	1111	1111111111	228.49	225	3.48	
9	483	43	B	H32	N15	228-2345	W2	12	111	1111	1111111111	228.99	225	3.99	
10	483	43	B	H32	D23	229-2305	W2	12	111	1111	1111111111	229.96	225	4.96	
11	439	52	C	R32	N13	200-2030	W2	03		1222	2113 2	200.85	194	6.85	Medium (4/5) SS 3
12	439	52	C	R32	N15	201-0845	W2	03	222			201.36	194	7.36	
13	440	49	C	R34	N11	201-1150	W2	04	1			201.49	191	10.49	
14	440	49	C	R34	N13	201-1950	W2	04	111	111	1111 1331	201.83	191	10.83	
15	440	49	C	R34	N14	201-2330	W2	04	111	1111	111 12132	201.98	191	10.98	
16	455	46	D	D31	N15	210-2308	W2	09	222	122	232222232	210.96	208	2.96	
17	525	60	E	M32	D21	260-1115	W2	19	111	1222	2112122222	260.47	256	4.47	Full (1.0) SS 3
18	525	60	E	M32	D23	260-2345	W2	19	111	1122	2112222222	260.99	256	4.99	
19	525	60	E	M32	D24	261-0350	W2	19	111	1122	2112222222	261.16	256	5.16	
20	525	40	E	M32	N21	260-1115	W2	19	111	1111	1111211111	260.47	256	4.47	
21	525	40	E	M32	N24	260-2345	W2	19	111	1221	121121221	260.99	256	4.99	
22	487	50	E	M33	D14	234-2330	W2	14	111	1111	1111111111	234.98	225	9.98	
23	489	39	E	M34	N22	238-2128	W2	15		12		238.89	228	10.89	
24	489	39	E	M34	N23	239-0915	W2	15		122	222 3 2	239.39	228	11.39	
25	487	43	E	M34	N15	234-2330	W2	14	111	1111	1111111111	234.98	225	9.98	
26	489	51	E	M31	D23	239-0915	W2	15	111	1111	11111	239.39	237	2.39	
27	453	46	F	H41	N15	208-2326	W2	07	2	122	222222232	209.98	208	.98	Low SS 4
28	532	60	G	Q42	D14	266-1236	W2	23	111	1122	2111222222	266.53	256	10.53	Medium (2/3) SS 4
29	533	61	G	Q42	N14	266-1830	W2	24	2	1111	22	266.77	259	7.77	
30	532	56	G	Q42	D14	266-1236	W2	23	111	1111	1111111111	266.53	259	7.53	
31	533	57	G	Q41	N13	266-1830	W2	24	111	1	222211 13	266.77	265	1.77	
32	540	60	H	M43	D15	269-1250	W2	29	111	1122	2112222222	269.53	256	13.53	Full SS 4
33	541	40	H	M43	N15	269-2000	W2	30	111	1112	1111111112	269.83	256	13.83	
34	540	43	H	M43	D15	269-1251	W2	29	111	1111	1111111111	269.54	252	17.54	
35	541	51	H	M43	N15	269-2000	W2	30	111	1111	1 122212	269.83	252	17.83	
36	538	60	I	H52	D15	268-1250	W2	27	111	1122	2112222222	268.53	256	12.53	Low SS 5
37	535	43	I	H51	D15	267-1255	W2	25	111	1111	1111211111	267.54	252	15.54	
38	494	43	J	P51	N13	242-2215	W2	15	111	112	111111	242.93	225	17.93	Full SS 5
39	543	60	K	M53	D15	270-1304	W2	31	111	1122	2112222222	270.54	256	14.54	
40	543	43	K	M53	D15	270-1305	W2	31	111	1111	1111111111	270.55	252	18.55	
41	547	43	K	M55	D21	273-1117	W2	34	111	1111	1111111111	273.47	252	21.47	
42	547	43	K	M55	D25	274-0832	W2	34	111	1111	2222222222	274.36	252	22.36	
43	547	51	K	M55	N21	273-1130	W2	34	1	1122	2112122222	273.48	252	21.48	
44	547	51	K	M55	N25	274-0832	W2	34	111	2222	2222222222	274.36	252	22.36	

3. Findings and Conclusions

The evaluation of motion interference with a wide range of general functions, mission functions, and experimental tasks was not as fruitful as hoped, because data were either inadvertently missed, hastily checked, or anomalously evaluated, and were not adequately covered at some conditions.

Examination of tabulations of all the results does not show progressively worse interference with increasing motion severity, as was the case in Phases I and IA (Ref. 6). Most of this anomaly is due to the anomalously good ratings given by two of the few crewmen who survived to higher sea states. The data from Subject 60 were felt to be most representative of the true situation. Even for him the severe motion conditions (SS 5) affected most of the rated mission and experimental tasks less than Full SS 3!

This portion of the experiment must be written off as a failure due to poor execution.

4. Recommendations

Despite the failure of the Habitability Evaluation Questionnaire to produce good data during Phase II, we strongly recommend its retention for future habitability investigations whether in a simulator or at sea, using better procedures to insure a valid data base. Among these procedures should be taped and/or written instructions to the subjects as to the proper care and criteria to use in filling out the forms (which, at the most careful pace, only takes a few minutes). There must be a requirement (and means) for the Test Conductor to check the completeness of each form on the spot so that it can be completed if necessary. (These procedures were used in Phases I and IA, although in an informal manner, and good evaluation data were obtained.)

Fewer evaluations per run, with more care and completeness in each, are also recommended.

SECTION IV

SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

A. COMPENDIUM OF SPECIFIC FINDINGS

Numerous specific findings and conclusions are scattered throughout this report. Here we will collect them in a concise summary. Those reading only this section for results are advised to first read the brief overview of the experiment and conditions given in Section I.

1. ECM Tracking

Our interpretation of the measured ECM Tracking performance under the various motion conditions is as follows.

a. At some small level of motion (on the order of 0.05 to 0.10 G_z rms), the performance of knob/dial tracking tasks begins to fall off towards a 15-20 percent decrement "plateau" at intermediate levels of acceleration in the range from 0.15 to 0.30 G_z rms. This occurs regardless of the detailed spectrum, as long as the major power lies in the 1-3 Hz range.

b. With experience in a given sea state, most subjects gradually learn to cope with the motion disturbances and can bring performance up toward, but not to, the static baseline level. Noting that the fitted "learning time constant" across all static runs was about three days, it is suggested that a similar time may be required to readapt to each new motion condition. However, the lack of any systematic effect of Day 1 versus Day 2 does not support this hypothesis.

c. An apparent anomalous performance trend, of improved ECM task performance at the higher sea states and amplitudes relative to lower sea states, was fairly consistent among the few subjects available for comparison. It may have been due to this readaptation-to-motion effect, even after each crewman's static performance asymptote had been reached. For example, Full Sea States 4 and 5 were always the last to be experienced, and they showed the highest scores under motion. This result has important implications on future experimental designs involving visual-motor tasks under motion conditions; presentation order must be randomized to avoid this anomaly.

d. Differences among subjects are greater than decrements in ECM task performance due to the applied motions, and the better performers generally seemed to adapt more readily to motions. This conclusion suggests that high-performing crewmen should be used when motion conditions are severe, and implies further investigation of the hypothesis.

e. Eight crewmen out of twenty were sufficiently incapacitated by motion sickness as to be unable to continue their runs. ECM tests completed by them just before aborting their runs show that performance was maintained at levels typical of the motion condition until severe nausea and emesis (or retching) occurred, at which point it dropped to 50-60 percent of their static performance. These data provide hard evidence that adequate performance on short but demanding visual-motor tasks can be maintained despite moderate kinetosis.

f. Significant correlations between ECM Tracking scores and Dual-Axis Tracking task parameters were observed, and are described in the latter's section.

2. Dual Axis Tracking

The Dual Axis Tracking Task proved sensitive to motion conditions despite a wide range of individual skill levels and a roughly 6-day learning time constant. In nearly every case where a matched static-motion comparison was made, each crewman showed a decrement in tracking accuracy, σ_e^{-1}, relative to corresponding static runs. This decrement was only 16 percent at two-thirds SS 3, but jumped to 50-56 percent between two-thirds SS 4 through full SS 5.

A strong correlation ($\rho = 0.8$-0.9) between tracking accuracy, σ_e^{-1}, and characteristic frequency, f_0^+, was found across all static tests. The cause was analyzed as being a predominantly limit cycle mode of operation due to the high friction and detented finger stick and the absence of a strong external forcing function. Thus the diminished accuracy can be related to increased "perceptual indifference thresholds," and the decrease in characteristic frequency is due to bigger visual-motor delays and control pulse duration. Evidence of both effects was found under most motion conditions.

Vertical tracking accuracy was roughly 40 percent worse than horizontal accuracy for all conditions, including most static cases. The absence of worse heave-induced-impairment of vertical vs. horizontal tracking (as had been expected) is thought to be due to the arm-rested-on-table configuration of the finger/stick system (which suppressed direct biomechanical feedthrough from heave motion) and to the apparent lack of differential perceptibility of vertical vs. horizontal displayed errors (despite readily observed head bobbing). This finding is important for weapon tracking on SES.

Good correlation (ρ = 0.80-0.85) was found among various crewmen between Dual Axis Tracking accuracy or characteristic frequency parameters vs. the separate ECM Task scores run on the same day. However, variations within an individual over time or due to motion per se were not so well correlated, partly due to differential learning rates between tasks (T = 3 vs. 6 days).

3. Keyboard Operations

The Keyboard task involved a chain of visual-motor subtasks potentially sensitive to SES motion effects, such as transcription of verbally transmitted data, operation of a small wall-mounted mincomputer with arm outstretched, copying results from the small digital display on the minicomputer, and verbal transmission of the results. Not too surprisingly, this complex array of manipulations resulted in continued learning throughout most of the static and motion runs, thereby making difficult the analysis of the relatively small effects of SES motions.

The specific findings were as follows:

a. Under static conditions the median of all subjects' average time to complete the Keyboard task continued to improve from about 125 to 80 sec, with an 8 day learning time constant.

b. On the average, there were much fewer than 1.0 errors per multipart problem and fewer than 1.0 restarts per problem, with no apparent pattern to the differences among crewmen under either static or motion conditions. The scarcity of such errors precluded statistical analysis, and the somewhat unexpected absence of any apparent trends in such errors precludes any positive statement as to motion effects.

c. Occasional restarts tended to skew the distribution of computation times so that median computation times for a given subject are a more appropriate measure of Keyboard performance than mean values.

d. Relative to their corresponding pre- and post-motion static tests, in the only two conditions where sufficient data exist to make matched pair comparisons, motion increased the typical Keyboard computation times by 24 percent in medium SS 4 and by 46 percent in full SS 4. However, these increments barely exceeded the typical standard deviation among subjects, and so were not statistically significant.

e. In SS 4 conditions, one group of subjects who indicated "no symptoms" of kinetosis retained Keyboard task performance within 20 percent of static levels, while the others who had severe motion sickness dropped more than 40 percent in performance.

It is concluded that SES motions of the type simulated would decrease performance on well-trained Keyboard tasks only slightly, on the order of the scatter among various operators. Subjects who were not prone to kinetosis showed no motion interference while some subjects who were strongly susceptible showed more severe loss in performance, probably due to indirect psychophysiological effects of motion sickness. In view of the fact that an extremely small keyboard was used as a "worst likely case," any more reasonable keyboard design having larger, heavily detented keys, would probably not suffer in performance under these typical SES motions.

4. Lock Opening Task

Fine-motor operations were tested by the lock opening task which measured the time and number of restarts to open a very low-friction, four-combination security lock.

Analysis of the highly skewed and multipeaked histograms revealed peaks at a basic opening time (about 20 sec) and multiples thereof indicating successive restarts. Under static conditions, the basic opening time was around 19 sec with 45 percent restarts, for a median lock opening time of 26 sec among all subjects.

Only the least severe motion condition (low SS 3 with .13 rms G_z acceleration) showed little change from static. Under all other motions there was some increase in opening time and restarts for most subjects and conditions, but no systematic pattern which could be correlated with motion properties. The tendency for worse performance under motion was highly significant statistically ($p < 0.001$; one tailed Signs Test).

5. Maintenance Task

A task simulating electrical equipment maintenance and repair operations was performed by many subjects in most motion conditions. Because the operations involved complex maneuvers such as: manipulation of a densely packed circuit board, simultaneously unsoldering and unwrapping with pliers a variety of thick wires wrapped to posts, and handling of fragile electronic parts without breakage; there was a wide range of individual performance and gradual improvement throughout the test period. Evidence was obtained that distinct, individual "styles" of work (wherein electronically experienced subjects often performed more slowly) accounted for much of the range of data.

The measure of performance was a weighted disassembly rate, $\dot{D}$, in parts/minute. About 75 percent of the cases (subject-conditions) showed a decrement in $\dot{D}$ under motion and 25 percent an increase in $\dot{D}$, with the median among cases going from 2.6 parts/minute static to 2.0 parts/minute under all motions; a roughly 20 percent impairment.

There was no systematic effect on $\dot{D}$ among various motion conditions, with even low SS 3 showing some decrement, in contrast to most of the pattern of previous tasks.

Although the crewmen found the task subjectively more trying under motion, their performance did not suffer seriously. This was traced to the intermittent and occasional (twice per minute) nature of the actual part removal process, so that appreciable increases in actual removal time did not impact strongly on the overall rate of performance.

It is concluded that SES-like motions of the type simulated would have relatively minor adverse effects on the performing of most electromechanical maintenance tasks on small equipment, even though the subjective workload would be greater.

6. Load Handling

The Load Task involved maneuvering a 14 pound (30 kg) black box (simulating a typical electronics rack) out of a canvas mailbag, handing it to a partner, moving about carrying it, standing and squatting, and (for

September only) sliding it into a simulated rack mount. Only subjective evaluations of the difficulty of performing these maneuvers were scored.

The subjects indicated no problems at any sea state under 0.20 G_z rms and only a few problems at full SS 5.

It is concluded that handling modest loads typical of electronics racks or storage boxes, having handles such that one hand can be used to carry the load and one hand for bracing the subject, will not cause appreciable problems in level maneuvers at conditions up to SS 5. At the higher sea states, stair, step, or ladder climbing will provide some difficulty while carrying such loads. This finding must not be extrapolated to other types of loads.

7. Kinetosis

The Kinetosis Ratings made at prescribed times or logged by the Test Conductor or Medical Officer showed the following trends:

- Roughly one-third to one-half of each team became sick or quit due to motion sickness in the various SS 4 or SS 5 conditions, where the MSI-weighted* rms heave acceleration, σ_{MSI}, exceeded about 0.05 g (corresponding to roughly more than 0.20 g rms, total). No emesis occurred in the few cases of low SS 3, where $\sigma_{MSI} = 0.02$ (total $\sigma_{g_z} = 0.13$).
- The correlation of worst Kinetosis Ratings during a run with σ_{MSI} was broadly scattered but not inconsistent with the trend of MSI vs. σ_{MSI}.
- There was evidence of a more gradual kinetosis progression in SS 3, a pronounced drop in SS 4, and a precipitous drop in SS 5. Six-hour runs would expose only about half of the potentially sick subjects in SS 3 and SS 4 but almost all in SS 5.
- The time course of terminal motion sickness towards emesis varied widely among sick crewmen, with a common tendency to have mild symptoms followed by a divergent drop to "severe nausea" or "emesis" levels with a 2-4 hour time constant.
- There was meager evidence for some adaptation to successive motion conditions by a few subjects who experienced enough conditions to yield relevant data.

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*MSI (Motion Sickness Index) ≡ Percent of crew sick in a given period. For MSI weighting concepts see pp. 100-102 herein and Refs. 4, 11, 12, 17.

The evaluation of symptoms of kinetosis revealed that in these self-reported (often incompletely) cases:

- The most commonly experienced symptoms were: "Yawn a lot (80%); "belch or burp" (64%); "headache" (56%); "salivate, swallow" (56%); and "nausea" (52%). (Vomiting was incompletely reported on the forms because subjects were incapacitated or had quit.)

- Only vague and weak correlations could be detected between severity of motion (i.e., σ_{MSI}) and symptom frequency, but part of this problem was due to the incomplete or anomalous nature of some data.

It is concluded that the kinetosis evaluations show a clear consensus that from one-third to one-half of a group of crewmen such as these (with little sea experience) would, within several hours, experience severe nausea or become sick in conditions where the MSI-weighted rms heave acceleration exceeds about 0.05 g (roughly, total G_z rms > 0.19 g with appreciable content below 0.6 Hz). Below σ_{MSI} = 0.02 g, few would be affected. This conclusion impacts the design of heave alleviation systems and operating conditions. A small percentage of crewmen were naturally kinetosis resistant and had good performance under severe motion conditions. They provide evidence that an SES could be operated in severe sea states, without heave alleviation, albeit with a small, select crew.

These kinetosis results are somewhat less optimistic than the Phases I and IA results (with experienced, motivated crewmen), but may in fact be unduly pessimistic because the naive crewmen tested may not be typical of near-future SES crews.

Other, more diagnostic, medical and stress aspects of the crew's kinetosis can be found in Vols. 4 and 5 (Refs. 19 and 18).

8. Environmental Factors

With few exceptions, the typical ratings for Vibration, Sound, and Temperature influence on crewmen's sense of Well Being were "No Influence" or "Slightly Unpleasant" throughout all test conditions. The histograms actually suggest a slight improvement with higher sea state, but this is probably due to the fewer, more tolerant subjects surviving to these conditions.

As was true for the effects on Well Being, the interference of Sound and Temperature on Shipboard Duties was negligible, the medians being between "No Influence" or "Slight Interference." Vibration is evaluated as having "Slight" to "Moderate Interference" for Medium SS 3 and Low SS 4 conditions, but most of the low ratings were traced to a few subjects. As in the well being ratings, the whole body motions produced the largest effects and with similar trend of the median ratings.

There are too few data to have a really sound median trend, and those at the higher sea states were biased towards the motion sickness resistant subjects. Consequently, we have not attempted any correlation of the Well Being or Interference ratings with total rms G_z or σ_{MSI}.

9. Interference with Specific Tasks

The evaluation of motion interference with a wide range of general functions, mission functions, and experimental tasks was not as fruitful as hoped, because data were either inadvertently missed, hastily marked, or anomalously evaluated, by many subjects.

Examination of tabulations of all the results does not show progressively worse interference with increasing motion severity, as was the case in Phases I and IA (Ref. 6). Most of this effect is due to the anomalously good ratings given by two of the few crewmen who survived to higher sea states. The data from Subject 60 were felt to be most representative of the true situation. Even for him the severe motion conditions (SS 5) were rated as affecting the mission and experimental tasks less than Full SS 3!

B. OVERALL CONCLUSIONS AND RECOMMENDATIONS

The following overall conclusions are drawn from the foregoing results, with emphasis on potential SES habitability problems. (Detailed recommendations are in appropriate foregoing subsections and are too lengthy to be repeated here, but overall recommendations have been included.)

1. By far the dominant problem for the relatively inexperienced crewmen involved was motion sickness (kinetosis) which afflicted a majority of them at one condition or another.

2. Use of an MSI-weighted rms heave acceleration, σ_{MSI}, per Refs. 4 or 17, seems to produce ranking of the conditions similar to the kinetosis experience of more typical subjects.

3. At the lowest condition tested (Low SS 3 wherein $\sigma_{g_z} = 0.13g$ and $\sigma_{MSI} = 0.021$ g) there was little kinetosis; at a range of intermediate conditions including: Medium and Full SS 3, and Low and Medium SS 4, a large fraction (from 1/3 to 1/2) of the crewmen experienced severe nausea or emesis, but there was no systematic pattern among these conditions. A few subjects proved sufficiently kinetosis resistant to take Full SS 5 without emesis, and two of these went through a 48 hr run without kinetosis problems. Thus these data emphasize the idiosyncratic nature of motion sickness and the importance of crew selection.

4. The conditions giving appreciable kinetosis to these inexperienced subjects were characterized by rms G_z from 0.19 to 0.28 with σ_{MSI} from 0.05 to 0.13. Attentuation of the motions in the frequency range of 0.1 to 0.6 Hz, such as to reduce σ_{MSI} to below 0.03 should reduce most of the kinetosis problems. However, the data herein are insufficient to more precisely prove this conclusion.

5. At all conditions for which sufficient data exist [except for (2/3) SS 3], there were appreciable decrements in visual-motor-task performance which are on the borderline of operational significance (e.g., 50+ percent increases in missile tracking error and lock opening times, 30 percent reduction in ECM tracking bandwidth, 20+ percent increases in keyboard operations and maintenance times). However, these decrements seldom achieved statistical significance because they are comparable to the inter-subject variations due to skill and learning.

6. There was not as much covariation of either Visual-motor Task performance or motion ratings with increasingly rougher sea conditions as was experienced in Phase I and IA. There was repeated evidence that performance started to deteriorate near the Low (2/3) SS 3 condition (where $\sigma_{g_z} = 0.13$ g); thereafter the decrement remained roughly constant for the other conditions up to Full SS 5. Despite the data from two kinetosis-resistant subjects, showing gradually improving visual-motor performance at SS 5, the debriefing comments and observations on the subjects while running, suggest that typical performance decrements would start to get worse beyond $\sigma_{g_z} = 0.20\text{-}0.25$ g. Runs by more typical and sea experienced crewmen are needed to check this suspicion.

7. Crewmen compensated for motion interference by increased mental and physical effort, as evidenced (weakly) by their Habitability Evaluation Questionnaires. Better methods for quantifying and logging this compensatory effort must be employed in future simulations.

8. In many cases the best performers under static conditions proved to be the most resistant to performance impairment by severe motion. This observation has important implications for SES crew selection, training, and rough water operating procedures; and it deserves careful investigation in future SES simulations or operational tests.

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APPENDIX

DATA FORMS

PHASE II OPERATOR'S DATA SHEET

RUN NUMBER: ____________ CONDITION: ________________ TASK: ___________________

CREWMAN M: ______________________________

Date	Time		Score	Comments
	Start	End		

CREWMAN S: ______________________________

Date	Time		Score	Comments
	Start	End		

KEYBOARD TASK DATA FORM FOR CREWMAN

Crewman ______________ Date ____________ Time of Day ____________

DATA GIVEN						CALCULATE				
RANGES				BEARING	OWN SPEED	INTERCEPT TIME	INTERCEPT RATE	TARGET SPEED	REL. HEADING	NUMBER OF RESTARTS
r_2 n. miles	r_1 n. miles	t_2 sec	t_1 sec	B deg	S_s kt	T sec	$\dot{R}$ kt	S_T kt	H deg	

HABITABILITY EVALUATION QUESTIONNAIRE

Note: Numbers in parentheses are used for scoring; Not on subject's form

RUN No._____

PHASE II

CREWMAN__________ DATE: ___/___/___ (YEAR MONTH DAY) TIME __:__ HRS. INTO MISSION _____

(Put any additional comments on reverse side.)

A. KINETOSIS (MARK THE SCALE)

LEVEL:	RATING	
No Symptoms	0	(1)
Stomach Awareness	1	(2)
Mild Nausea	2	(3)
Moderate Nausea	3	(4)
Severe Nausea	4	(5)
Emesis or Retching	5	(6)

COMMENTS: __________

CHECK YOUR TENDENCY TO:

	NONE (1)	SOME (2)	PRONOUNCED (3)
1 Yawn a lot			
2 Salivate, swallow			
3 Belch, burp			
4 Sweat			
5 Malaise			
6 Skin pallor			
7 Weakness, trembling			
8 Headache			
9 Nausea			
10 Vomit or gag			
11 Loss of appetite			
12 Constipation			
13 Lethargy			
14 Sore muscles			
Other_____			

B. OVERALL ENVIRONMENTAL RATINGS (MARK THE SCALE WHERE APPROPRIATE)

EFFECT ON YOUR WELL-BEING BY:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
PLEASANT	Very	(1)			
	Slightly	(2)			
NO INFLUENCE		(3)			
UNPLEASANT	Slightly	(4)			
	Moderately	(5)			
	Extremely	(6)			
INTOLERABLE		(7)			

INTERFERENCE WITH SHIPBOARD DUTIES BY:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
IMPROVEMENT	Much	(1)			
	Slight	(2)			
NO INFLUENCE		(3)			
INTERFERENCE	Slight	(4)			
	Moderate	(5)			
	Extreme	(6)			
INCAPACITATING		(7)			

C. SPECIFIC TASK INTERFERENCE (RANK THE DEGREE OF INTERFERENCE THAT THE ENVIRONMENT HAD ON THE TASKS BELOW: 0 = NEGLIGIBLE (1); 1 = MODERATE (2); 2 = EXTREME (3))

GENERAL FUNCTIONS:

EAT: HAND FOOD (SANDWICH)__; THICK FOODS__; LOOSE FOODS__;

DRINK: FROM CLOSED CONTAINER__; OPEN CUP__; POUR HOT COFFEE__;

READ: LARGE PRINT__; FINE PRINT__; FINE DIAGRAMS__; CALCULATOR READOUTS__;

WRITE: LARGE PRINTING__; SMALL PRINTING__; SCRIPT__; FINE DIAGRAMS__; PLOTTING__;

REST: RELAX, SNOOZE IN CHAIR__; SLEEP IN BUNK, UNRESTRAINED__; SLEEP IN BUNK, RESTRAINED__;
GO TO SLEEP QUICKLY__; AWAKE REFRESHED__;

MOVE ABOUT: WITH HANDHOLDS__; UNAIDED__; CLIMB LADDERS__; DESCEND LADDERS__;

CARRY LOADS: WITH TWO HANDS__; ONE HAND__; UP AND DOWN LADDERS__;

LAVATORY: WASH HANDS__; TOILET--SITTING__; TOILET--STANDING__; SHOWER__;
RAZOR SHAVE__; ELECTRIC SHAVE__;

RECREATION: CARD GAMES__; MODEL KITS__; SEWING REPAIRS__; TV__;

MISSION FUNCTIONS:

READ DISPLAYS: DIGITAL__; ON CRT__; ON METERS__;

CONTROL TASKS: SWITCHES__; PUSH BUTTONS__; KEYBOARDS__; STEERING__;

EXPERIMENTAL TASKS:

NAV. PLOTTING__; COLLISION AVOID__; MISSILE DETECT.__; CRYPTO__; ACUITY__; LOCK-OPENING__;
ECM TRACKING__; 2-AXIS TRACKING__; KEYBOARD__; ELECTROMECHANICAL REPAIRS__;

FORM III-B

PHASE III COMFORT RATINGS

IRIG Day: ____
or

Crewman: ____ ________________ Date: ___/___/___ Time ___:___ Hrs. Into Mission ______ Run No. _____
YEAR MONTH DAY

DEFINITIONS:

No symptoms — Feel the same as you do with no motion.

Stomach awareness — Lump in throat or gut, slightly queasy.

Nausea — Feeling the need to vomit

Mild — queasiness, vague urge to vomit

Moderate — strong urge to vomit

Severe — ready to vomit at any moment

A. KINETOSIS RATING

Level (Defined Above): Check One

Level		Check One
No symptoms	1	
Stomach awareness	2	
Mild nausea	3	
Moderate nausea	4	
Severe nausea	5	
Vomiting	6	

Comments: ________________

SYMPTOMS

Check Your Present Tendencies:	NONE	SOME	SEVERE
Yawn a lot			
Salivate, swallow			
Belch, burp			
Sweat			
Feel ill & depressed			
Paleness of skin			
Weakness, trembling			

Check Your Present Tendencies:	NONE	SOME	SEVERE
Headache			
Nausea or vertigo			
Vomit or gag			
Loss of appetite			
Constipation, nonurination			
Sluggishness			
Sore muscles			
Other ________			

(Put any additional comments on reverse side.)

B. OVERALL ENVIRONMENTAL RATINGS (Mark each scale once, where appropriate)

Effect On Your Sense of Well-Being Due To:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
Pleasant	Very				
	Slightly				
No Influence					
Unpleasant	Slightly				
	Moderately				
	Extremely				
Intolerable					

Interference With Shipboard Duties Due To:

		WHOLE BODY MOTION	VIBRATION	SOUNDS	TEMP.
Improvement	Much				
	Slight				
No Influence					
Interference	Slight				
	Moderate				
	Extreme				
Incapacitating					

FORM III-A

PHASE III TASK INTERFERENCE EVALUATION SHEET

IRIG Day ______ Run No. ___________

Crewman: ______________________ Date: ___/___/___ Time ___ ___ Hrs. Into Mission ___________

YEAR MONTH DAY

Check how much the motion environment interfered with your ease of doing the following tasks (or would likely interfere if task not actually performed during the run). Check "No Basis" if you have no previous or present basis on which to judge. (Check one column.)

LIVING FUNCTIONS

		INTERFERENCE: NO BASIS	NONE	SOME	EXTREME
EAT:	Hand foods				
	Thick foods				
	Loose foods				
DRINK:	From closed container				
	From open cup				
	Pour hot coffee				
READ:	Large print				
	Fine print				
	Fine diagrams				
WRITE:	Large print				
	Small print				
	Script (words)				
	Draw fine diagrams				
REST:	Relax, snooze in chair				
	Sleep in bunk, unrestrained				
	Sleep in bunk, restrained				
MOVE ABOUT:	With handholds				
	Unaided				
	Climb ladders				
	Descend ladders				
CARRY LOADS:	One hand, with other braced				
	Two hands				
	Up and down ladders				

		INTERFERENCE: NO BASIS	NONE	SOME	EXTREME
LAVATORY:	Wash hands				
	Toilet, sitting				
	Toilet, standing				
	Shower				
	Electric shave				
	Razor (blade) shave				
RECREATION:	Card games				
	Model kits				
	Sewing repairs				
	TV watching				
OTHER:	____________ (Specify)				

MISSION FUNCTIONS

		NO BASIS	NONE	SOME	EXTREME
DISPLAYS:	Digital (Numbers, letters)				
	Radar or sonar scopes				
	Oscilloscope signals				
	Read meters (Dials)				
	Navigation charts				
MANUAL TASKS:	Switches				
	Pushbuttons				
	Keyboards				
	Steering or tracking				
	Helmsman				
	Electromechanical repairs				
	Binocular search				
	Other ____________				
EXPERIMENT TASKS:	Radar vigilance				
	ECM (dial-knob) tracking				
	Dual-Axis (CRT + stick) tracking				
	Other ____________				